MAY, 1960

Welding Journal

See Page 473

IN THIS ISSUE

Welding on High-pressure Gas-transmission Pipe Lines..... 473
Gas Metal-arc Welding of Low-carbon Steels..... 478
Service Failure of Pipe Weldments..... 488
1959 Adams Lecture—The Science of Arc Welding, Part II..... 177-s
Photoelastic-coating Technique Measures Stress Distribution.. 191-s
Time-Temperature Parameters in Corrosion of 18Cr-8Ni Welds 199-s
Some Observations on Kinzel and Drop-weight Tests..... 205-s
Welding of Galvanized Steel..... 212-s
Hot-cracking Test for CO_2-shielded Welds..... 219-s
Index to Advertisers..... 564

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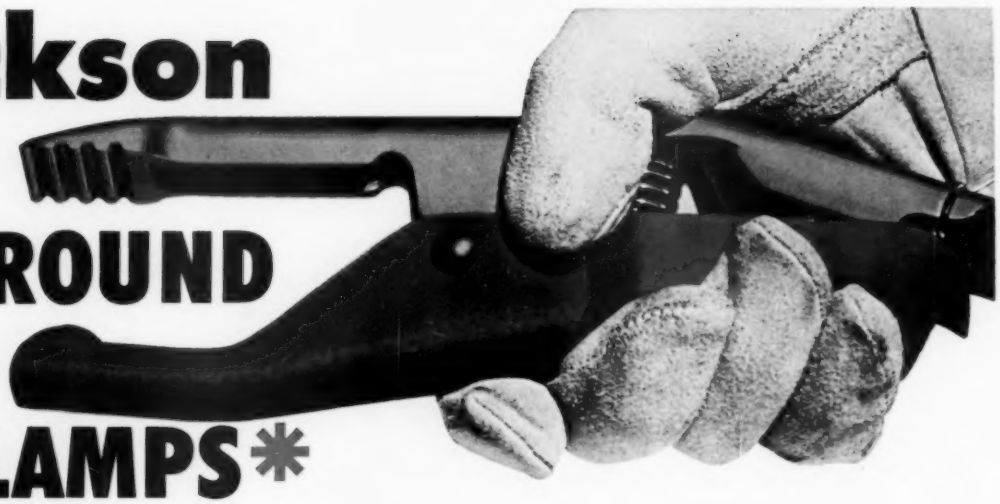

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VOLUME 39 • NUMBER 5 • MAY 1960

Welding Journal

Technical Papers Items and Reports

Welding on High-pressure Gas-transmission Pipe Lines, by Robert R. Wright and Robert S. Ryan 473
Gas Metal-arc Welding of Low-carbon Steels, by G. Christopher and R. C. Becker 478
Service Failures of Pipe Weldments, by Helmut Thielsch 488

Practical Welder and Designer

Gas Tungsten-arc Welding Aids Construction of Manned Research Vehicle, by W. L. Arter 496
Repairs in Modern Railroading . . . Throttle Costs, Highball Profits, by C. R. Strutz and E. D. Uecker 497

Society and Related Events

Press-Time News 462
Welding Zones 464
World-Wide Welding News 466
Editorial—Run Hard While Ahead, by Frank L. LaQue 471
Society News 499
Invitation to Authors 509
Section News and Events 512
New Members 526
News of the Industry 528
Personnel 536
Employment Service Bulletin 539
Abstracts of Current Patents 540
Current Welding Literature 542
New Literature 544
New Products 550
Reader Information Card 563
Index to Advertisers 564

Welding Research Supplement

1959 Adams Lecture—The Science of Arc Welding, Part II, by Clarence E. Jackson 177-s
Research News 190-s
Photo Elastic-coating Technique for Determining Stress Distribution in Welded Structures, by F. Zandman 191-s
Time–Temperature Parameters Affecting Corrosion of 18Cr-8Ni Weld Metals, by Thomas J. Moore 199-s
Some Observations on the Kinzel and Drop-weight Tests, by S. A. Agnew, M. D. Mittelman and R. D. Stout 205-s
Welding of Galvanized Steel–Cracking Mechanisms, and Development of Solutions, by John F. Rudy 212-s
Hot-cracking Test for CO_2-Shielded Metal-arc Welds, by P. W. Ramsey, R. A. Keidel and J. N. Kuhr 219-s

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PRESS-TIME

NEWS

...about
...People
...Welding
...Products

UEC Fund Drive Stepped Up as Building Starts to Rise

Steel erection has begun, as every phase of the construction of the United Engineering Center is reported on schedule or a little ahead. The 20-story building will face the United Nations Plaza at 47th St., New York City, when completed. Finished to date are the footings, basement walls, floor slabs and the first stages of plumbing.

Meanwhile, early April returns of the fund-raising campaign for the Center, plus other funds, show the over-all total at about five-sixths of the $12 million-dollar goal. Of the 18 engineering societies participating, two have reached 100% of quota and five others range from 74 to 91% of goal.

AWS National Secretary Fred L. Plummer reported returns to April 1st of slightly over one-third of the SOCIETY'S total pledge of $60,000. Mr. Plummer urged all sections to cooperate with Vice-president Al Chouinard who has been working continuously to bring in the AWS share. Mr. Plummer pointed out that the UEC building is not in any sense to be regarded as a social center for the area but is to be the production headquarters for the emanation of vital engineering services. It will house the business offices of the staffs, the meeting rooms of numerous working committees and the editorial staffs concerned with the publication of major engineering literature. In urging members to support this campaign he also pointed out that, in contrast with the old building, the new Center will reflect on the economic status and the community standing of the engineering profession as a whole.

Details of construction, recently made public, reveal that the exterior of the structure will be sheathed in stainless steel and glass on three sides. The west side will be limestone. The steel framework will be of welded construction. The lobby, opening on 47th St., will be walled in marble with the floors of terrazzo. Two corridors lead from the lobby to meeting rooms and dining rooms on the first floor. On the east side, a display area of 6235 sq ft will feature ceiling-height windows. Approximately half the ceiling height will be 15 ft with the other half rising 22 ft. Movable partitions in this area, as well as in meeting rooms and dining rooms will permit conversion of space to special purposes. Four elevators along the west wall will be capable of speeds of 700 fpm.

Provisions for future expansion of office space has also been made on the northwest side of the building. The expansion could add as much as 8500 sq ft of floor space from the 3rd to the 8th floors and 6000 sq ft from the 9th to the 12th.

Altogether, the Center will rise 283 ft above street level including 18 floors of office space and two of mechanical equipment. A basement provides space for a dining room seating 350, a serving counter and an employees' lounge.

Substructure for the main lobby and elevator bank located at west side of site. In the background is the Carnegie Endowment for International Peace

New Officers Elected by AWS

R. D. Thomas, Jr., has been elected President of the American Welding Society for the 1960-1961 term. He will assume office on June 1, 1960, succeeding the current President, Charles I. MacGuffie. Mr. Thomas previously held the office of first vice-president.

This year 3 vice-presidents without seniority were elected. They are: John H. Blankenbuehler, A. F. Chouinard, and Clarence E. Jackson.

The complete results of all elections are published on pages 499-501.

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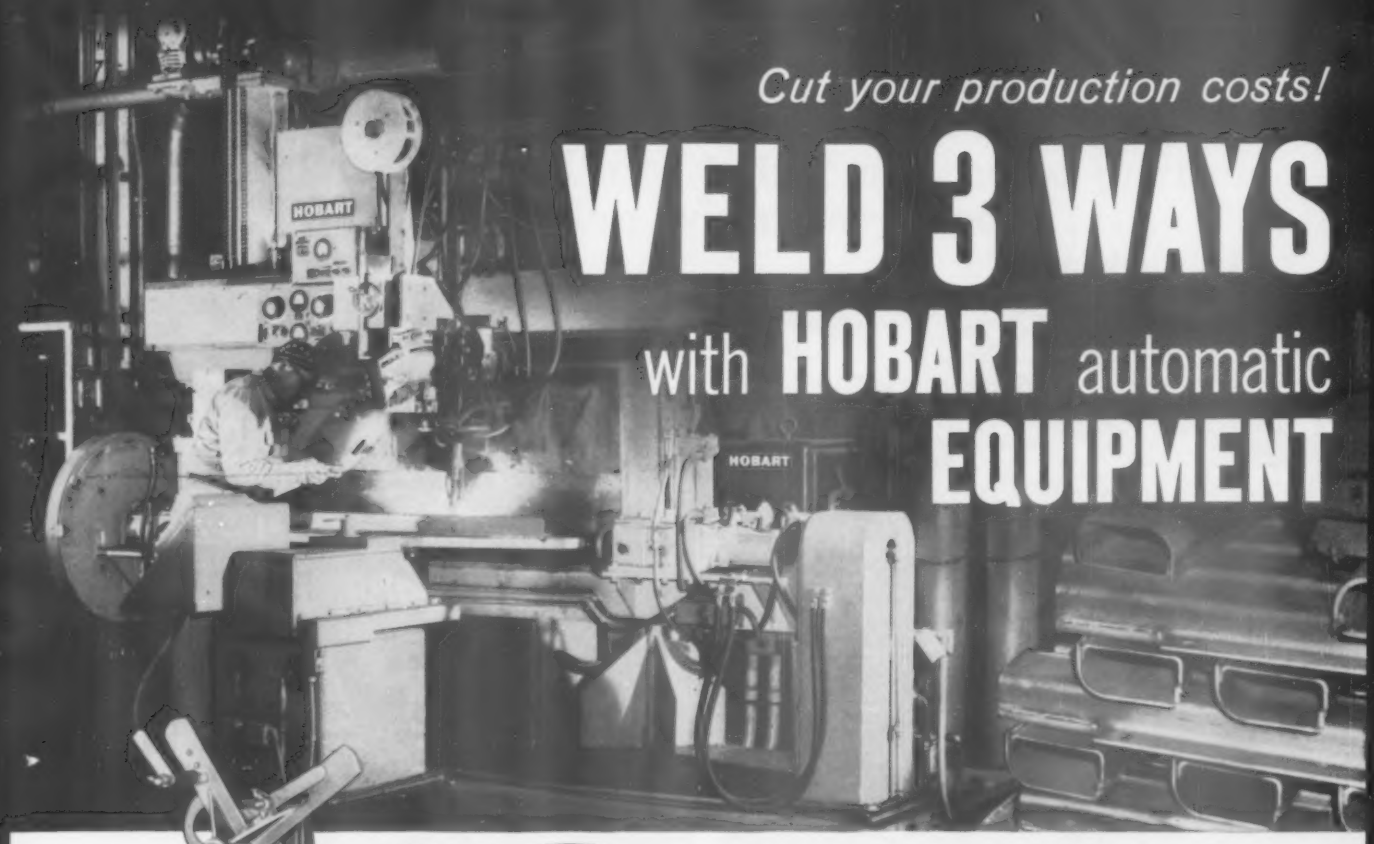

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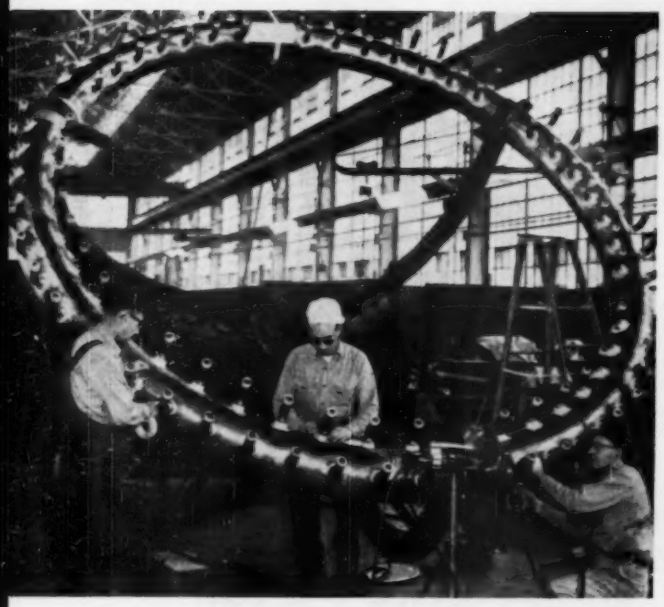
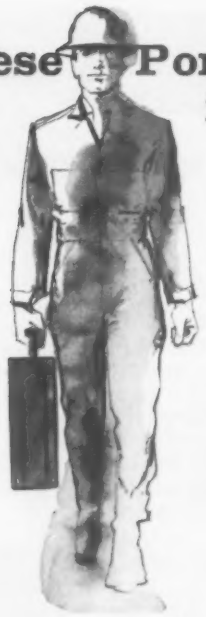


Showing an interesting adaptation of a positioner, this $13^{1}/_{2}$-ft.diam outlet header was fabricated at the Dravo Corp., Marietta, Ohio, plant. Made of Type 304 stainless steel, $10^{3}/_{4}$ OD x 0.750-in wall, the header will be used in the new Hanford plutonium recycle test reactor, Richland, Wash.

(Right) Four 141-ft welded-plate girders placed on 8-ft centers are the steel supporting members of an overpass on Ohio's North-South throughway in Ashtabula Co. The $^{7}/_{16}$-in. steel plate (ASTM-A-373) was fabricated and erected by Builders Structural Steel Co., Cleveland, Ohio. (Courtesy Jones and Laughlin Steel Corp).

Rectangular structural tubing finds an interesting application in this truck boom. Box sections are made from formed channels welded together. (Courtesy of Espro Tubing Division of Union Asbestos Rubber Co.)



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WORLD-WIDE WELDING NEWS

by Gerard E. Claussen

AUSTRIA

The May 1959 issue of the Austrian magazine, *Schweisstechnik* (Vienna), contains two articles on welded chemical equipment. To clad Cr-Mo steel valves with stellite, an intermediate layer of austenitic steel or high-chromium ferritic steel is deposited to avoid cracks. Root porosity and cracks in deep groove welds are avoided by providing a small hole parallel to and just below the root into which the root layer penetrates.

BELGIUM

The Belgian magazine *Acier-Stahl-Steel* for June 1959 contains an essay by Prof. Massonnet on the desirability of plastic design for mild steel structural frames made up of fairly large double-T sections, rigidly connected and stressed by quasi-static loads. Savings through plastic design often are undermined by problems of instability. It is hoped that the Belgian Standards Institute will organize a committee to draft a specification for plastic design.

CZECHOSLOVAKIA

The Czechoslovakian welding magazine *Zvaranie*, for July 1959 describes rotating bend fatigue tests on bolted flanges for shafts. Welding the ends of the bolts to the flange raised the fatigue strength. Shortage of cobalt has led to the introduction of a series of low-cobalt stellites for high pressure vessel fittings. One series contains 9–11.5% Co with 25–30% Cr, 3.5–5% W, 1.3–1.6% C or 26–31% Cr, 11–14% W, 1.9–2.4% C. The other series contains 30–35% Co with 25–30% Cr, 3.5–5% W, 1.2–1.5% C or 26–31% Cr, 11–14% W and 2.1–2.6% C. The remainder is iron in every composition.

A third article reports measurements of hardness, impact value, intergranular corrosion and ferrite content of two austenitic weld metals heated 1 hr at 1830 or 2430° F with and without reheating 1 or 100 hr at 1020 to 1560° F. Each weld metal contained 18% Cr, 9.5% Ni, 0.10% C. One contained 1% Mo, 0.67% Cb. The other had 2.06% Mo, 0.08% Ti. Magnetic phase increased as the homogenizing temperature was raised, but impact value was minimum after reheating to 147° F. for 100 hr. The columbium-bearing weld had better resistance to intergranular corrosion than the low-titanium weld.

The August issue describes a hard-surfacing alloy called Real NB, similar to RN_1Cr-C and containing 3.15% B, 21.50% Cr, 52.64% Ni, 17.46% Fe, 1.29% C and 2.78% Si. The hardness did not fall appreciably below the initial 530 Vickers even after 10,000 hr at 1290° F.

EAST GERMANY

Production Planning

The East German welding magazine, *Schweisstechnik*, for July 1959 featured that country's program to develop its chemical industry. Training of welding and corrosion specialists, and bringing about close cooperation among industries, technical schools and research institutes were the principal immediate objectives.

A review of means to increase productivity in shipyards to assist in raising the standard of living to the extent envisaged by the seven-year plan, showed that bad weather from November to March reduces welding output by 75% compared with the rest of the year. The submerged-arc process was particularly susceptible to bad weather, yet this process offered the greatest advantages in productivity.

The Technical Division of the East German Central Welding Institute with a staff of 45 was formed to work with industry on production problems. The seven groups within the Division are (1) Methods: modern methods must be used, (2) Automation, (3) Materials for welding, (4) Nondestructive tests, (5) Equipment testing, (6) Standards and patents, (7) Inspection of factories. The latter group decides whether a factory is qualified to produce work to a given specification level.

The August issue records the results of the competition in 1958 among the four East German shipyards in increasing the use of submerged-arc welding. The competition resulted in increasing the percentage of submerged-arc welding from 30 to 40% for a 3000-ton freighter, and from 32 to 46% for a 10,000-ton freighter.

Fillet Strength

The penetration and fatigue strength of $^1/_4$-in. fillets were found to be the same with $^3/_{16}$-in. as with $^5/_{32}$-in. low-hydrogen electrodes. The fillets were made in the flat position and had a fatigue strength in pulsating tension of 12,800 psi. The welds penetrated to the apex of the joint. The results showed that $^3/_{16}$-in. electrodes could replace the $^5/_{32}$ in. size.

CO_2 Welding

The Central Welding Institute made a thorough evaluation of CO_2 welding in all positions using the standard electrode (0.08–0.12% C, 0.8–1.0% Si, 1.0–1.4% Mn, 0.030% max S, 0.030% max P) and soda water CO_2 (99.3 vol % CO_2 about 70 mg/liter moisture). For vertical and overhead welding the electrode was 0.047 in. diam, while for other positions the diameter was $^1/_{16}$ or 0.079 in. The current was 90–120 amp. in vertical and overhead positions and for the root layer in horizontal fillets and butt joints in the flat position. Up to 380 amp. were used for filling butt and fillet joints in the flat position.

Shipyard Figures

Time and material studies of four ships from 120 to 3500 tons in an East German shipyard showed that 22–40 welder hr, 60 to 77 lbs of electrodes and 880–1300 cu ft of gases were required per ton of ship weight. Conversion from manual to submerged-arc welding resulted in better utilization of yard area.

Experiments with a corona-discharge torch consisting of a tung-

Dr. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

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sten electrode surrounded by nitrogen, CO_2, argon or hydrogen and powered by a 1-kw triode at 27 kc showed that the flame was too unstable for practical use. However, tungsten and molybdenum wires, steel sheet 0.032-in. thick, refractories and quartz could be melted or welded.

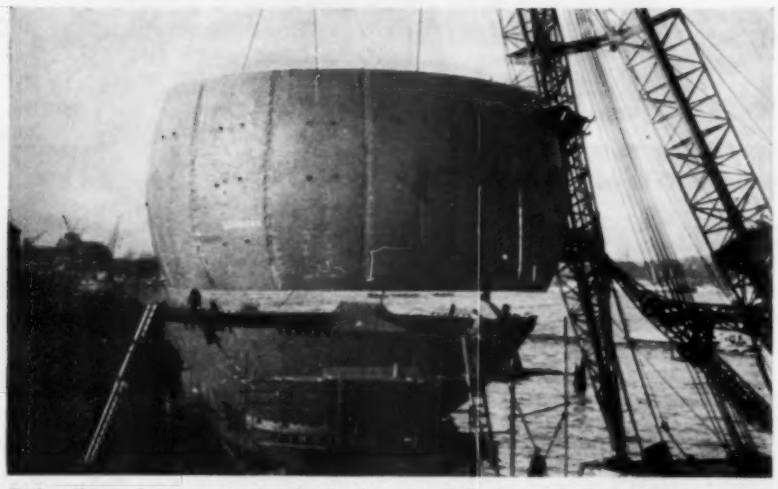
RUSSIA

Resistance Welding

Resistance welding is the theme of the entire July 1959 issue of *Svarachnoe Proizvodstvo*. The level of automation in welding in Russia is expected to rise from 11% in 1959 to 40% in 1965. In line with this aim, resistance welding is expected to increase 250%. About 60% of the joints in cross country pipelines 21 in. in diam are made by resistance welding with contour transformers, and the method has been applied to 28-in. pipe and larger. Resistance welding also is widely used in welding railroad rails and tapered roller bearings. The fourteen articles in this issue deal with the following subjects:

1. Large resistance welding machines, including a 2400-kva machine (with circuit diagram) for welding locomotive bodies $^1/_{16}$–$^5/_{32}$ in. thick.
2. A summary of eleven recent research studies at the Paton Institute, include flash welding of rails and the circumferential joints of pipes 21-in. diam, $^3/_8$-in. wall, high-speed seam welding, condenser-discharge welding of Tee joints, and automatic heat treatment of welded joints in wire rope.
3. Flash welding of rails ($2^1/_2$–6 min to weld rails 75–150 lb/yd) and fatigue testing, which showed best results for joints in which the foot was normalized after welding.
4. A survey of spot and seam welding aluminum alloys, describes an electromagnetic clutch for seam welding wheels, and prevention of corrosion of welds.
5. The projection welding of hot rolled steel, contact resistance, strength of joints.
6. Manufacture of flash-welded reinforcing bars for concrete construction.
7. Condenser-discharge welding of bicycle frames, circuit diagram of welding machine, oscillograms, microstructure and strength of joints.
8. Five condenser - discharge welding machines for spot and seam welding sheets from 0.0002–0.020-in. thick are described.
9. Seam welders are described for joining lengths of strip in strip mills.
10. Ultrasonic inspection of spot and seam welds.
11. Circuit diagrams are explained for a spot- and a seam-welding machine for sheets 0.002–0.020 in. thick.
12. The seam welding (300 cycle power) of steel tubing and pipe $1^1/_4$–4 in. diam, $^1/_{16}$–$^5/_{32}$-in. wall is described.
13. Curves are given relating the electrical and thermal properties of steel bars $1^1/_2$–3 in. diam to the distribution of temperature during resistance butt welding.
14. Tables of machine settings and surface etching are given for spot and seam welding titanium 0.024–$^1/_8$ in. thick.

NETHERLANDS



Fitting the main course during fabrication of a 41-ft diam spherical pressure vessel. (Courtesy Constructie Werkplaatsen en Machinefabriek Braat N. V., Rotterdam)

WEST GERMANY

The June 1959 issue of the German magazine, *Werkstatt Und Betrieb*, contains a research report on a process patented in 1952 to eliminate porosity in arc welds by applying a transverse magnetic field to the weld metal while it is cooling from AR_3 to AR_1. The present tests were made with bare and covered electrodes. An effect was observed only with the bare electrode at 800 oersteds, a-c field. The diamagnetic characteristics of the gas in the blowholes caused them to align themselves with the field and to be expelled by the field from the weld puddle. The authors attributed no practical value to the process.

Current Effects

The rectification factor of a-c welding arcs in argon was studied at the Materials Institute of the Rhine-Westfalen College in Aachen and was reported in the July 1959 issue of the West German magazine, *Schweissen Und Schneiden*. The rectification factor was defined as the ratio of current densities at the cathode on succeeding half cycles. For two tungsten electrodes the rectification was, of course, unity. For pairs of unlike electrodes: tungsten–aluminum, and tungsten–austenitic stainless-steel the factor was 5×10^{16} and 5×10^4 respectively, in agreement with calculations from the Richardson equation. The factor for tungsten–aluminum was reduced to only 3 by superimposed high frequency, which changed the character of the discharge from arc to glow.

Oil Pipe Line

The construction in Germany by American methods of the oil pipe line from Wilhelmshaven to Cologne involved vertical-down welding with 6010 electrodes. This was an unusual experience for the German engineers, who completed the job successfully.

Vertical-down welding was compared with vertical-up with 6012 electrodes for V and X butt joints in $^5/_8$- and 1-in. mild-steel plates. The appearance was better, the shrinkage distortion was less and the mechanical properties were better with vertical-down welding. A cost analysis favored the vertical-down process, but whereas $^1/_8$- and $^5/_{32}$-in. electrodes were used for up-welding, $^5/_{32}$- and $^3/_{16}$-in. electrodes were used for down-welding.

Failure of any part of a missile—be it the mighty Atlas, Jupiter or Thor—can mean failure of the mission. That's why the complex connections in the ducting systems of these and other missiles are silver brazed. These connections must stand up under 6,000 psi; they are tested to 12,000 psi.

In lines made to specifications by Flexonics Corporation, Maywood, Illinois, silver brazing joins a corrugated flexible pressure carrier, a braid sleeve and a coupling nipple—all of stainless steel; it permits joining all of these elements of the assembly without danger of annealing the pressure-carrying flex or the restraining braid as welding might do.

Assemblies designed for 6,000 psi operating pressure are required to withstand a 12,000 psi test and take four times their normal operating pressure before failure. They may also be required to pass a flame test in order to meet specifications.

The silver-brazed connections are used on hydraulic and pneumatic systems, fuel drain lines and vent tubes. Some of these applications involve rigorous service with extreme pressure shocks accompanied by sudden elevations of temperature, which may go from −60° to 400-600° F in a matter of seconds.

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Intercontinental Atlas missile being made ready for launching.

Close-ups of missile section, showing silver alloy brazed ducting assembly.

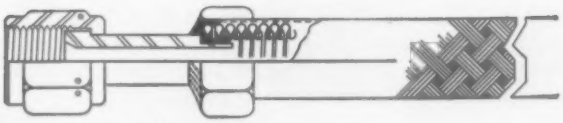

Diagram of pressure carrier.

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Run Hard While Ahead

Every so often one hears that some industry or practice has "come of age." I suppose the welding industry has "come of age" a half dozen times already and probably will keep on doing so repeatedly in the future. The trouble is that the "ages" keep changing. They change in terms of materials that characterize them, in terms of new demands that require new materials and new ways of joining them and in terms of new levels of quality that present new challenges to the leaders of the welding industry.

Joining by methods akin to welding probably did not have much to do with progress in the stone age, but certainly joining was important in the bronze age and even more so in the iron age. Over the years we have been in the "railroad age," the "automotive age," the "aircraft age," the "chemical age," the "atomic age" and most recently the "space age." While it is too much to say that welding made these several ages possible, it is nevertheless true that the contribution of welding was substantial and, in some instances, vital. As the demands of these successive ages on materials and their fabrication become more and more severe and more and more decisive, the importance of progress in welding will become more and more evident, and no prolonged period of satisfaction with established practices can be anticipated.

Many others have emphasized, properly, the necessity of developing amongst other things sources of trained personnel capable of making the most effective uses of advances in welding processes and equipment. If we are to continue to make progress, there is another essential requirement. This is the maintenance of an open mind that will accept new ideas and view new developments in materials and processes in the most constructive fashion. We must try to make them work rather than to succumb to a temptation to reject them because they present new problems. At all times we must insure that welding materials, equipment and processes are reliable for the purposes for which they are being used. Nevertheless, we must cultivate a healthy attitude of dissatisfaction with the progress we have made and thus insure that the welding industry will continue to make the progress of which it is capable. We must *run hard* while we are ahead.

Frank L. LaQue

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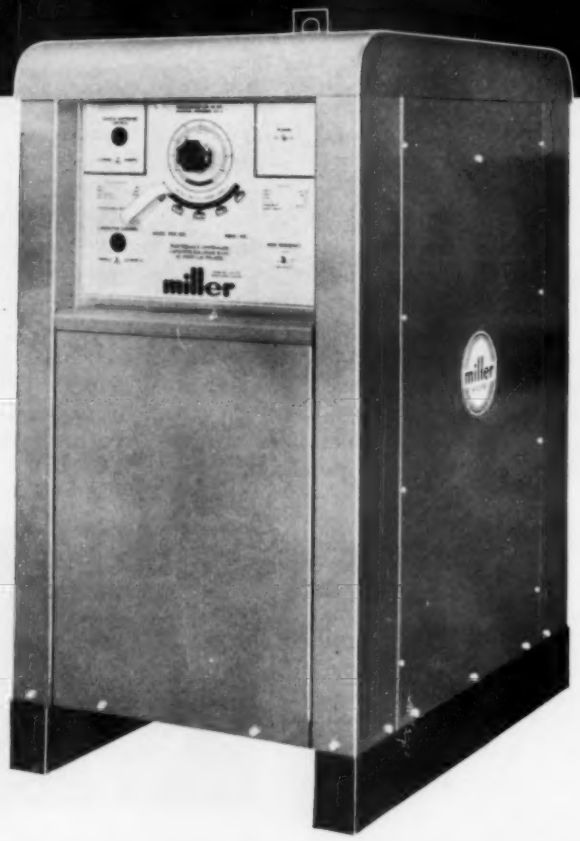

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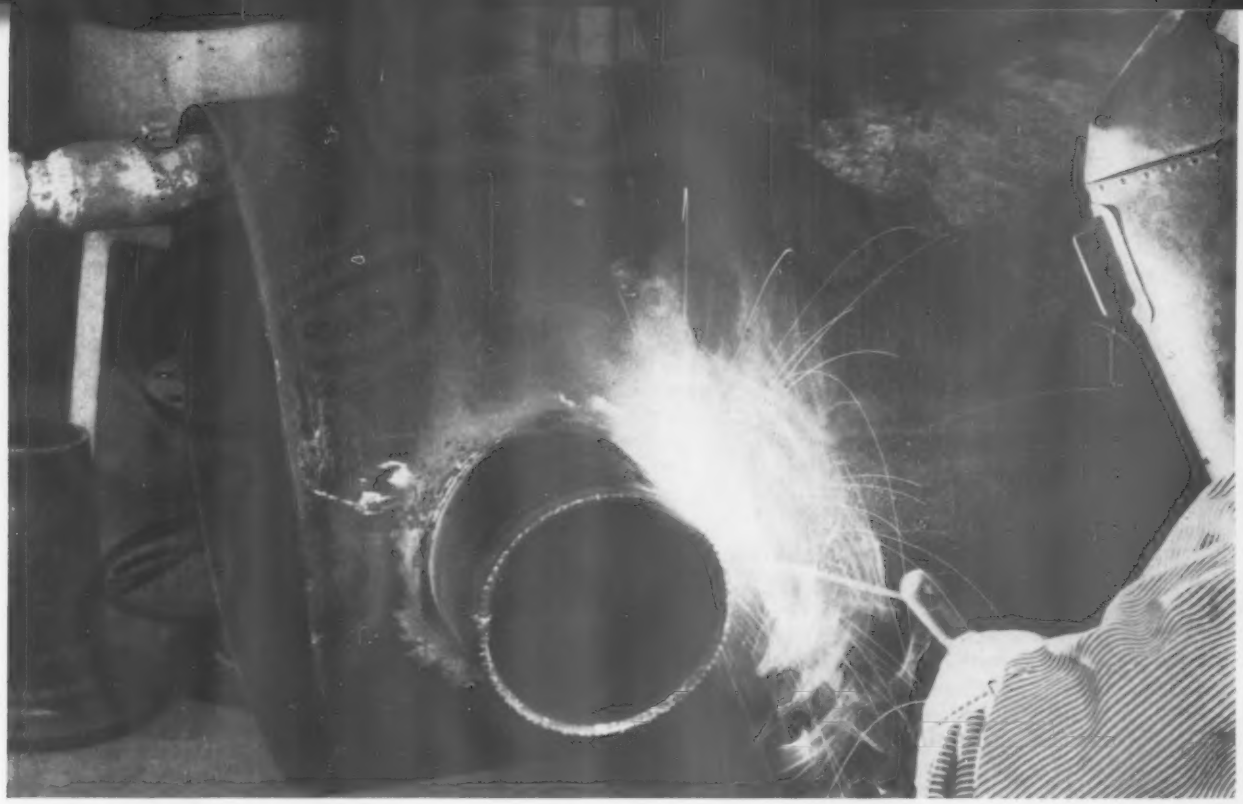

Welder making a test weld

Procedure is developed for producing sound, full-penetration welds for branch connections, and particularly hot taps, when

Welding on High-Pressure Gas-Transmission Pipe Lines

BY ROBERT R. WRIGHT AND ROBERT S. RYAN

In recent years, the gas-transmission industry has become the unfortunate, although necessary, recipient of problems of its own making. These problems range widely in their variety, but for purposes of this paper, we are concerned with a particular problem. This problem came as a result of the pipeline industry's constant struggle to keep construction costs down. In an effort to balance increased gas throughput, pipe-wall thickness, pipe sizes, pipe metallurgy and construction costs, the industry has turned more and more to higher-strength pipe steel.

It is impossible to anticipate the size and location of all the branch connections which will be made to a pipe line during its service life. It follows, therefore, that there will be a number of branch connections which will have to be made to the pipe line *after* it has gone into service. Now, the previous enthusiastic efforts to hold the construction costs in line by selecting higher-yield-strength pipe steel presents an operating problem.

The branch connections must be made while gas is flowing through the main line in order to maintain uninterrupted service to existing customers. The possibility for underbead cracking exists when making these connections due to the quenching effect of the flowing gas. Therefore, the Columbia Gas System has developed a procedure for welding branch connections onto these new pipe line materials. The purpose of this paper is to describe the new welding procedure and compare it with the previous procedure.

Hot Taps

The welding of a branch connection onto a pipe line which contains gas under pressure is called a "hot tap." Hot taps are necessary in order to continue service to the existing customers while making provision for new customers. Interrupting the flow of gas in a pipe line is very inconvenient to an existing customer and quite expensive for the company. If

Robert R. WRIGHT and Robert S. RYAN are associated with Columbia Gas System Service Corp., Columbus, Ohio.

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an existing customer's service is interrupted, each commercial, industrial or residential location must be visited twice—first, to shut off all the valves and second, to purge the line and light all the appliances.

The first step in making a hot tap is to clean the area on the pipe where the connection is to be made. A flange is welded to the branch pipe. The branch pipe is cut to fit the carrier pipe and welded in place. A full-opening type valve is attached to the flange. A pressure-tight drilling machine, shown in Fig. 1, is then flanged to the valve and, with the valve open, the drill travels through the valve, through the branch connection and drills a hole in the carrier pipe. The drill is then retracted, the valve closed and the branch line is connected to the valve.

Procedure Used with API 5L Materials

API Standard 5L, Specification for Line Pipe, which is one of the standards covering pipe-line steels, provides for pipe with a minimum yield strength of 35,000 psi and a minimum tensile strength of 60,000 psi. This material has been welded quite successfully for many years in accordance with a welding procedure that is fairly standard throughout the industry. A widely used joint design for making hot taps in this material is shown in Fig. 2 (a), (b), (c) and (d). A $^1/_{16}$-in. land and root opening is required with a bevel ranging from 50 to 55 deg. All welding is downhill, with a $^1/_8$-in. diam E6010 type electrode used for the stringer bead and a $^1/_8$ or $^5/_{32}$-in. diam E6010 type electrode used for the filler and cover passes. This welding procedure is satisfactory when welding API 5L materials because the chemical composition is essentially a mild steel and there is very little difficulty with underbead cracking.

Fig. 1—Hot-tap drilling machine

Why a New Welding Procedure Is Needed

API Standard 5LX, Specification for High-Test Line Pipe, provides that X52 pipe shall have a minimum yield strength of 52,000 psi and a minimum tensile strength of 72,000 psi for pipe 20 in. and larger with a wall thickness less than 0.312 in. The minimum tensile strength of other diameters and wall thickness is 66,000 psi. Although 52,000-psi minimum yield-strength pipe is the highest strength pipe completely specified by API Standard 5LX, 56,000-psi material has been approved by the API Committee but the chemical specifications have not been established.

The formation of cracks during and after welding can be attributed to many factors including hydrogen embrittlement and the formation of martensite. These two factors behave in a similar manner because cracking results and becomes more severe as the carbon and alloy contents increase and/or the cooling rate increases. Since this is true, the same remedial treatment will eliminate both problems. The treatment involves retarding of the cooling rate. In addition, the use of low-hydrogen electrodes is recommended to eliminate a considerable amount of hydrogen from entering the weld.

Hydrogen Embrittlement

The majority of the hydrogen that is available for absorption in molten weld metal is supplied from a high-humidity atmosphere, moisture on the pipe or in the electrode covering, and hydrogen producing compounds in the electrode covering. Investigators are not sure of the exact mechanism by which the hydrogen embrittles steel and causes cracking. It is generally thought that the heat of the welding arc dissociates the hydrogen into atomic hydrogen. In this state, hydrogen is readily soluble in steel and is absorbed in the molten weld metal. The higher the temperature, the more hydrogen the steel can absorb and, as the weld cools, the atomic hydrogen tries to escape. One avenue of escape is diffusion into the many small voids and cavities which are present in the weld metal and the heat-affected zone of the base metal.[1,2] Upon entering these voids and cavities, the atomic hydrogen changes to molecular hydrogen which, due to its larger molecular size, is unable to diffuse through the steel. This molecular hydrogen builds up tremendous pressures within the voids and cavities. Failure usually occurs when the stresses that are produced by these high pressures are coupled with other stresses, such as the shrinkage stresses of the weld metal.

A steel's susceptibility to hydrogen embrittlement increases with increased carbon, manganese and silicon content.[1] Normally, the weld metal is not affected by hydrogen embrittlement because it has a low-carbon content. Base metals with high-carbon and manganese contents are subject to this type of failure. Therefore, the cracking invariably occurs in the heat-affected zone of the base metal adjacent to the weld, and is commonly referred to as underbead cracking.

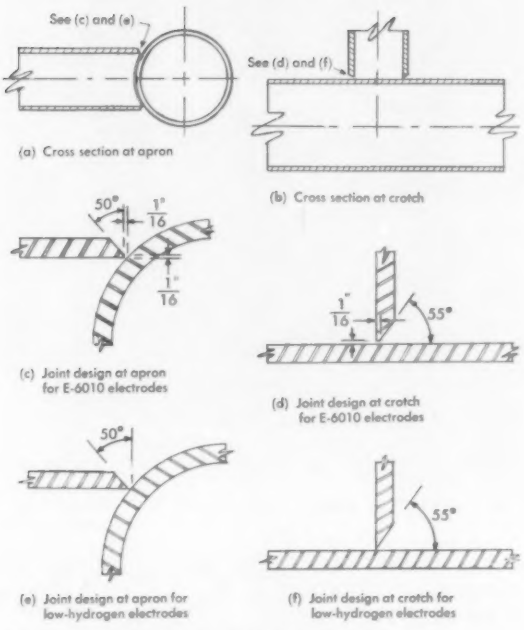

Fig. 2—Joint design for hot taps using E6010 and low-hydrogen electrodes

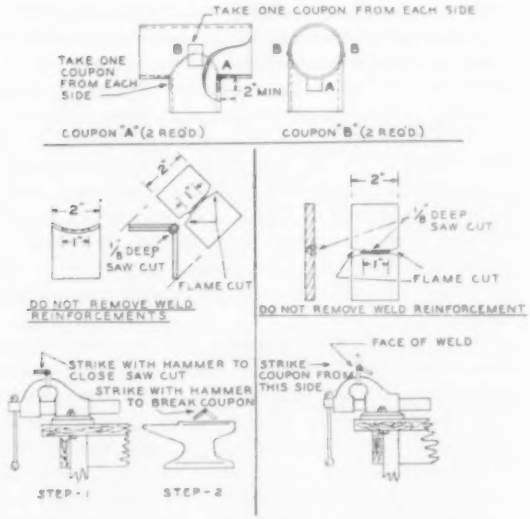
TAKE ONE COUPON FROM EACH SIDE
TAKE ONE COUPON FROM EACH SIDE
2" MIN
COUPON "A" (2 REQ'D)
COUPON "B" (2 REQ'D)
1/8" DEEP SAW CUT
FLAME CUT
DO NOT REMOVE WELD REINFORCEMENTS
DO NOT REMOVE WELD REINFORCEMENT
STRIKE WITH HAMMER TO CLOSE SAW CUT
STRIKE WITH HAMMER TO BREAK COUPON
FACE OF WELD
STRIKE COUPON FROM THIS SIDE
STEP-1
STEP-2

Fig. 3—Location of test coupons and method of testing

The lower the ambient temperature, the faster will be the cooling rate. If the cooling rate is retarded, there is sufficient time for a large majority of the hydrogen to escape[3] by diffusing out of the weld metal into the atmosphere. It is for this reason that welds made at ambient temperatures associated with the summer months are not as likely to crack as those made at ambient temperature associated with the winter months, assuming no preheat is used. Preheating to 200° F is normally sufficient to retard the cooling rate and allow the hydrogen to escape from the weld metal to the atmosphere.

Formation of Martensite

The welding arc heats the steel to temperatures which cause structural changes to occur within the metal. If the metal is cooled slowly, ductile structures are formed; however, if cooled rapidly, martensite, a hard and brittle structure, will be formed. Generally, as the carbon and alloy content of the pipe increase, the possibility of forming martensite increases. Also, as the carbon content is increased, the martensite that is formed increases in hardness, and decreases in ductility. As this martensite forms, an expansion in volume takes place. The stresses which accompany this expansion, plus the shrinkage stresses of the weld, often cause cracking. The martensite, having low ductility, cracks because it is unable to deform in a manner to accommodate these stresses.

Weld metal is of a low-carbon content and is, therefore, not as susceptible to the formation of martensite as is the base metal. For this reason these cracks, as in the case of hydrogen embrittlement, occur in the heat-affected zone of the base metal adjacent to the weld and often are referred to as underbead cracks.

Hydrogen embrittlement and the formation of martensite are more predominant in high-chemistry pipe. A preheat of 200° F will normally retard the cooling rate enough to provide sufficient time for the hydrogen to escape from the weld to the atmosphere. This will also prevent the formation of martensite.

The increased strength of X-56 is obtained chiefly through increased carbon and manganese contents. An empirical formula which is used to determine the susceptibility of pipe-line steels to cracking is $C + Mn/4$. This is called the carbon equivalent of the pipe. Laboratory tests and field weld failures in pipe indicate that, if the carbon equivalent is 0.60 or more, cracking can occur to an extent that might seriously lower the strength of joints welded by normal construction methods.

As described above, preheat can be used very effectively in many applications to eliminate underbead cracking. However, there are a number of applications where preheat is not practical or feasible, such as hot taps. The flow of cool gas in a pipeline almost instantaneously removes any heat. Therefore, since hot taps must be made in high-chemistry materials with high-pressure gas flowing through the pipe line and quenching the weld, it was felt that a new welding procedure was needed.

Development of Procedure for Welding High-Chemistry Materials

Testing Procedure

The material used in this investigation consisted of 6-in. diam 0.280-in. wall, API 5L Grade B pipe, welded to 20-in. diam 0.250-in. wall, API 5LX 42 pipe. The weld was made with the connection held in the horizontal position as shown in the lead photograph. Two nick-break specimens were removed from the crotch section and two from the apron sec-

Fig. 4—Porosity encountered using E6010 joint design for low-hydrogen electrodes

Fig. 5—Entrapped slag

tion of the completed weld. The test coupons were removed and tested as shown in Fig. 3. As can be seen in the lead photograph, three welding positions must be used in completing this weld, i.e., flat, vertical and overhead.

Low-hydrogen electrodes were chosen for the filler metal because of their ability to eliminate underbead cracking. The change-over from the E6010 electrode to the low-hydrogen type presented a number of problems in the joint design. Therefore, a considerable amount of investigation was required in order to develop a satisfactory joint design for use with the low-hydrogen electrode.

Development of Welding Joint

Porosity, such as that shown in Fig. 4, was encountered when the joint design used with the E6010 electrode was used for low-hydrogen electrodes. This was attributed mainly to the fact that the $^1/_{16}$-in. root opening exposed the molten metal of the weld deposit in the stringer bead to the atmosphere. Therefore, it was decided to butt the branch connection tightly against the run pipe, leaving no root opening.

Past experience had shown that it was necessary to produce a full-penetration weld between the branch and run pipe for branch connections. Therefore, every effort was made to produce an equally sound, full-penetration weld in the API 5LX grades of pipe when using low-hydrogen electrodes.

Since the low-hydrogen electrode does not have deep-penetrating characteristics, the welding joint had to be designed accordingly. The shallow penetration was compensated for by grinding the bevel to a feather edge, rather than leaving a $^1/_{16}$-in. land. A bevel of approximately 55 deg enables the electrode to reach down into the root of the joint thus permitting 100% penetration. This bevel also enables the welding operator to hold a short arc which eliminates the porosity resulting from maintaining a long arc with low-hydrogen electrodes. The joint design that was developed from this investigation is shown in Fig. 2 (a), (b), (e), and (f)

Development of Welding Technique

During this investigation, both the uphill and downhill methods of welding were examined. With standard E6010 electrodes, the downhill method is preferred and is known to have a number of advantages for pipe-line welding. When welding downhill with low-hydrogen electrodes, the slag, which is more fluid than that of the E6010 electrode, runs ahead of the arc and makes it very difficult to obtain 100% penetration. In addition, slag is entrapped, as shown in Fig. 5. When welding uphill, the slag runs back away from the arc, thus leaving the root of the weld joint readily accessible to the electrode. For this reason, the uphill method was adopted.

Many times, upon striking the arc, porosity is encountered during the short time it takes the welder to stabilize the arc and obtain a short arc length. This porosity can be eliminated by striking the arc ahead of the starting point and bringing the arc back to the starting point, at which time the arc is stable and there is a short arc length. Welding should then proceed over the point where the arc was struck. This technique eliminates any porosity which might result from the initial arc strike.

Various sequences of depositing the weld beads were used. A wide whipping action is not recommended because porosity often results. It was concluded that the bead method produces a better quality weld than any other method. As mentioned above, the welding groove must be such that the root of the joint is accessible to the electrode. Therefore, in some cases it is necessary to remove high spots on previously deposited weld beads to obtain this accessibility.

Cleaning was found to be extremely important

Fig. 6—Cross section of completed weld using new joint design

since low-hydrogen electrodes are not deep-penetrating electrodes. It is necessary to clean each bead very thoroughly, because any slag or foreign matter will be entrapped and will not burn out when depositing subsequent beads. Large gas pockets were noted to emanate from areas of entrapped slag. Therefore, an essential feature which should be emphasized repeatedly is that each bead be thoroughly cleaned of slag before depositing the next bead.

Electrodes Used

Electrodes $^{1}/_{8}$-in. diam. were used for the stringer bead while $^{1}/_{8}$ or $^{5}/_{32}$-in. diam. electrodes were used for the filler and cover passes,

The Columbia Gas System has a policy of periodically qualifying the electrodes of various manufacturers. In conformance with this policy, a number of electrodes conforming with the E6016, E7016, E6018 and E7018 specifications were tested. Some were more susceptible to porosity than others. For this reason an up-to-date list of acceptable electrodes is maintained.

In this investigation, welds were made with electrodes that had been dried in an oven as well as with electrodes that had not been dried. Oven-dried electrodes performed slightly better. However, the electrodes that had not been dried had been stored in the laboratory. In the field, electrodes will not be stored under such ideal conditions and will be much more liable to absorb moisture. Therefore, it is recommended that suitable precautions be taken to maintain the low-hydrogen content of the electrodes.

Often, low-hydrogen electrodes will have small areas of the covering chipped off as a result of handling. Also, the covering occasionally chips from the electrode during welding. When these areas reach the arc, they cause the arc to be very erratic, thus introducing porosity. Therefore, these defective electrodes should be discarded. If the covering chips off during welding, the welding should be stopped and the electrode discarded. Certain electrodes are more prone to chipping than others. It was found that electrodes containing iron powder were more susceptible to chipping than the conventional lime-covered low-hydrogen electrodes. The arc of the iron-powder low-hydrogen electrode had a tendency to wander, whereas the arc of the conventional lime-covered low-hydrogen electrode could more readily be directed into the root of the weld joint.

Determination of Wall Thickness

There are other inherent problems in connection with making hot taps. Consideration should be given to the possibility that corrosion may have reduced the wall thickness of pipe that has been in the ground for a number of years. In the absence of adequate equipment, a welder does not know the remaining wall thickness at the point where the welding of the hot tap is to be made. A number of companies determine the wall thickness at that point with an ultrasonic wall-thickness measuring instrument prior to starting to weld. If the wall is found to be too thin to permit welding, the location of the branch connection can be adjusted accordingly.

Conclusions

The following items summarize the results of the investigation to determine a welding procedure to produce sound, full-penetration welds for branch connections and particularly hot taps. Figure 6 is a cross section of a weld which was made in accordance with the procedure.

1. The branch pipe should have a bevel of approximately 55 deg with a feather edge.
2. The branch pipe should be butted tightly against the main line.
3. Conventional lime-covered low-hydrogen electrodes should be used.
4. The uphill welding technique should be used.
5. The arc should be struck ahead of the desired starting point and brought back to the starting point.
6. The weld passes should be beaded rather than weaved with particular care not to whip the electrode.
7. Every bead should be cleaned very thoroughly.
8. The electrode should be kept dry.
9. Chipped or otherwise defective electrodes should be discarded.
10. Ultrasonic wall-thickness measurements should be used to determine the location for making the hot tap.

Acknowledgment

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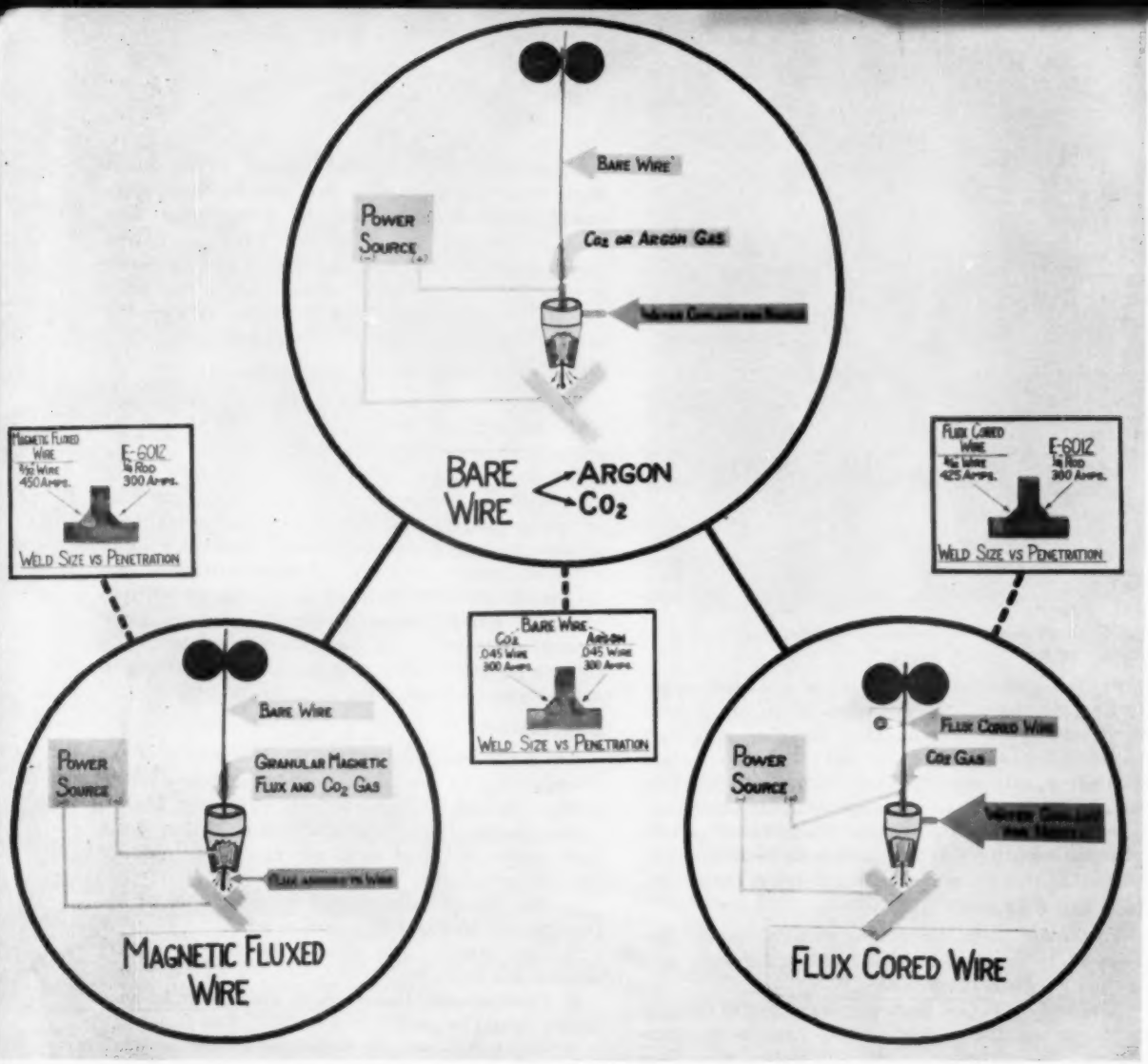

Gas metal-arc welding

Higher deposition rates, increased weld penetration and lower costs are the principal advantages in

Gas Metal-Arc Welding of Low-Carbon Steels

BY G. CHRISTOPHER AND R. C. BECKER

SYNOPSIS. From the utilization of the gas metal-arc processes in production and from numerous laboratory investigations, it has become apparent that their ultimate potential has not been fully realized. Suitable applications for the gas metal-arc processes are not taken advantage of or shown to be economical due to the lack of information or choice of process. In addition, full recognition of the greater fillet-weld strength of these processes has not been fully considered or applied.

This report contains the results of findings on the comparative welding-arc time and material cost of the gas metal-arc processes and covered electrodes. Also, data has been developed which shows the greater fillet-weld strength of the gas metal-arc processes as compared to E-70XX electrodes.

With the inherent penetration of the gas metal-arc processes, particularly where CO_2 is used, it is recom-

G. CHRISTOPHER is Welding Engineer and R. C. BECKER is Assistant General Supervisor of Welding Research, International Harvester Co., Manufacturing Research Department, Chicago, Ill.

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mended that the groove or fillet-weld joint be modified to obtain a greater efficiency from the standpoint of lower weld-metal requirements and increased production rates. Some groove and fillet-joint modifications are included in this report.

Introduction

In 1950, International Harvester Co. entered into a joint development program with a manufacturer of welding equipment pertaining to the application of the inert-gas-shielded metal-arc welding process to low-carbon steels.

Many problems were encountered; however, a great potential was foreseen in the use of the gas-shielded metal-arc welding processes for production applications. During the first few years, the development work involved only the use of argon as the shielding gas. Sufficient success was obtained that a number of units were used on production applications.

By using argon as the shielding gas, production welds were obtained having excellent appearance, free of spatter. An increased production rate per worker was also realized. Over-all cost reductions were, however, not outstanding due to the cost of the argon gas. This led to the investigation of other shielding gases, particularly CO_2.

Laboratory research involving the use of the CO_2-gas-shielded metal-arc processes has been very active and has resulted in many production applications since 1955. Due to manufacturing requirements that have arisen and the resulting developments by a number of welding-equipment manufacturers, CO_2-shielded metal-arc welding has become a family of welding processes. There are still unknown factors concerning these relatively new welding processes that must be investigated before their ultimate potential can be realized.

This report covers the results of three separate phases of investigation into gas metal-arc welding:

1. An investigation of selected cost and operating factors on four types of semiautomatic, gas metal-arc welding processes (bare wire–argon, bare wire–CO_2, flux-cored wire–CO_2, and magnetic-fluxed wire–CO_2) and four types of arc-welding electrodes (E-6012, E-6020, E-6024 and E-7018).

The purpose of this phase was to develop data which would assist welding and planning personnel in utilizing these new processes most economically. The results of this analysis showed that the gas metal-arc processes are capable of welding at much higher speeds compared to conventional covered electrodes. It is recognized that the arc-time component, weld-material cost, joint geometry and fit-up, base material, position of welding and weld cleaning are the factors on each job that will determine which process is the most economical to use.

2. An investigation of the design performance of fillet welds made with the CO_2 metal-arc process.

Fillet welds made with the CO_2 metal-arc process exhibit considerably more root penetration than fillet welds made with covered electrodes.

Such root penetration contributes to the joint strength. The purpose of this phase was to determine the amount of root penetration that is consistently obtained, the variables involved and to develop a fillet strength table for CO_2-shielded welds.

3. Modifications of fillet- and groove-joint design specifications that will take advantage of the inherent penetration that is obtained with the CO_2 metal-arc processes.

Investigation of Selected Cost and Operating Factors

Testing Procedure

A determination of the arc time and material used for four semiautomatic welding processes was carried out on $^1/_4$ to $^1/_2$-in. welds. The processes tested were: bare wire–argon; bare wire–CO_2; flux-cored wire–CO_2; and magnetic-fluxed wire–CO_2.* Four types of conventional covered electrodes were also tested: E-6012, E-6020, E-6024 and E-7018. The welding conditions used are shown in Table 1. These conditions are typical and representative of those used on production applications.

Deposition Rates

In general, the gas metal-arc welding processes have a deposition rate two to three times greater than is obtainable with covered electrodes. Figure 1 illustrates the difference found in the weld-metal deposition rates for the various processes and electrodes. It should be noted that the maximum, as shown, is more a range than a point, and should be considered relative rather than specific. The gas metal-arc processes have an average weld-metal dep-

*Magnetic-fluxed wire refers to process wherein a powdered flux is caused to adhere magnetically to the current-carrying electrode just prior to entering the arc.

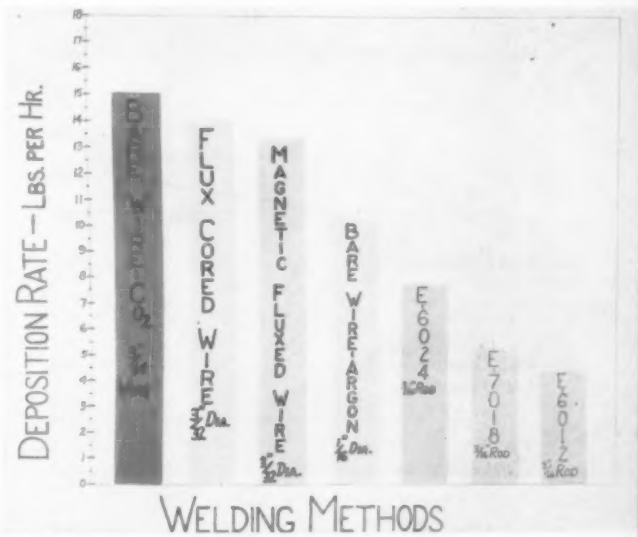


Fig. 1—Typical weld-metal deposition rates (lb per hr) for manual welding with the gas metal-arc processes and covered electrodes

osition rate ranging from 5 to 20 lb/hr in comparison to 2 to 11 lb/hr for covered electrodes.

Fillet-welding Speeds

Directly related to the higher weld-metal deposition rates is the increase in welding speeds on fillet welds which is experienced with the gas metal-arc process. Based on data which was determined after extensive work, both in the laboratory and in production, a set of comparative curves were plotted showing the arc time per inch of fillet for several fillet sizes and processes. The welding-arc time to deposit a specific size weld was calculated on the

Table 1—Welding Conditions Used for Fillet Tests

		Welding conditions						
Process or covered electrode	Fillet size, in.	Electrode diam, in.	Electrode melt-off rate, in./min.	Electrode deposition rate, lb/hr	Electrode efficiency, %	Approx. arc Voltage[b], Volts	Argon flow rate, cfh	CO_2 flow, cfh	Powder flux ratio
Bare wire–argon	1/4	1/16	200	10.2	98	29	25	..	...
	5/16	1/16	200	10.2	98	29	25	..	...
	3/8	1/16	200	10.2	98	30	25	..	...
	7/16	1/16	200	10.2	98	31	25	..	...
	1/2	1/16	200	10.2	98	32	25	..	...
Bare wire–CO_2	1/4	1/16	300	15.0	94	35	..	30	...
	5/16	1/16	300	15.0	94	36	..	30	...
	3/8	1/16	300	15.0	94	37	..	30	...
	7/16	1/16	300	15.0	94	37	..	30	...
	1/2	1/16	300	15.0	94	38	..	30	...
Flux-cored wire–CO_2	1/4	3/32	167	14.0	85	29	..	45	...
	5/16	3/32	167	14.0	85	30		45	...
	3/8	3/32	167	14.0	85	31	..	45	...
	7/16	3/32	167	14.0	85	31	..	45	...
	1/2	3/32	167	14.0	85	32	..	45	...
Magnetic-fluxed wire–CO_2	1/4	3/32	109	13.3	99	29[a]	..	35	0.5
	5/16	3/32	109	13.3	99	29[a]	..	35	0.5
	3/8	3/32	109	13.3	99	30[a]	..	35	0.5
	7/16	3/32	109	13.3	99	30[a]	..	35	0.5
	1/2	3/32	109	13.3	99	31[a]	..	35	0.5
E-7018 electrode	1/4	7/32	10.0	7.0	65	—	..	..	...
	5/16	1/4	9.2	8.7	65	—	..	..	...
	3/8	1/4	9.2	8.7	65	—	..	..	...
	7/16	1/4	9.2	8.7	65	—	..	..	...
	1/2	1/4	9.2	8.7	65	—	..	..	...
E-6012 electrode	1/4	1/4	9.0	6.7	60	—	..	..	...
E-6020 electrode	5/16	1/4	11.5	8.4	60	—	..	..	...
	3/8	1/4	11.5	8.4	60	—	..	..	...
	7/16	1/4	11.5	8.4	60	—	..		...
	1/2	1/4	11.5	7.4	60	—	..	..	...
E-6024 electrode	1/4	5/16	11.5	5.7	64	—	..	..	...
	5/16	1/4	9.4	10.8	64	—	..	..	...
	3/8	1/4	9.4	10.8	64	—	..	..	...
	7/16	1/4	9.4	10.8	64	—	..	..	...
	1/2	1/4	9.4	10.8	64	—	..	..	...

[a] Tests were conducted using a short gas nozzle.
[b] DCRP, constant potential power supply was used with all gas metal-arc processes and AC for covered electrodes.

basis of the electrode deposition rate of the various processes and the volume of weld metal required per inch of fillet. Figure 2 shows the bare wire-CO_2 process to have the highest welding speeds as compared to the other methods. The bare wire–argon process had the lowest speeds of welding in comparison to the other gas metal-arc processes. A comparison of the welding-arc time for making a $^1/_4$-in. fillet weld (extracted from Fig. 2) illustrates the differences in welding speed that can be expected from the various processes:

Process or electrode	Arc time (min) per inch of $^1/_4$-in. fillet
$^1/_4$-in. E-6012	0.110
$^7/_{32}$-in. E-7018	0.105
Bare wire–argon, $^1/_{16}$ in.	0.065
Bare wire–CO_2, $^1/_{16}$ in.	0.045
Fluxed-core wire, $^5/_{32}$ in.	0.050
Magnetic-fluxed wire, $^5/_{32}$ in.	0.052

Weld-material Costs

Welding material costs for the gas metal-arc processes are generally higher than for covered electrodes. The cost values were developed in dollars per inch of fillet weld for several fillet sizes ranging from $^1/_4$ to $^1/_2$ in. The total cost values illustrated in the curves of Fig. 3 represent the cumulative cost of weld materials, electrodes, wire, gas and powder flux. These values should be considered as relative rather than absolute since they cannot reflect the fluctuating cost of weld materials.

The bare wire–CO_2 process, as shown in Fig. 3, has a lower weld-material cost per inch of fillet as compared to the other processes. The bare wire–argon process has the highest cost of material per inch fillet. An example taken from Fig. 3 illustrates the comparative cost difference of the various welding methods for depositing a $^1/_4$-in. fillet weld:

Process or electrode	Material Cost per inch of fillet
$^1/_4$-in. E-6012	$0.0026
$^7/_{32}$-in. E-7018	0.0034
Bare wire–argon, $^1/_{16}$ in.	0.0056
Bare wire–CO_2, $^1/_{16}$ in.	0.0027
Fluxed-core wire, $^5/_{32}$ in.	0.0050
Magnetic-fluxed wire, $^5/_{32}$ in.	0.0048

Design Performance of Fillet Welds Made with the CO_2 Metal-arc Processes

General

The use of semiautomatic gas metal-arc welding has increased significantly in recent years. Reliable equipment has become available which will permit rapid and repetitive welding with consistent and dependable quality.

One of the major advantages of the gas-shielded metal-arc process—improvement in design performance—has generally been overlooked. This is particularly true of fillet welds where current design practice is based entirely upon data obtained for

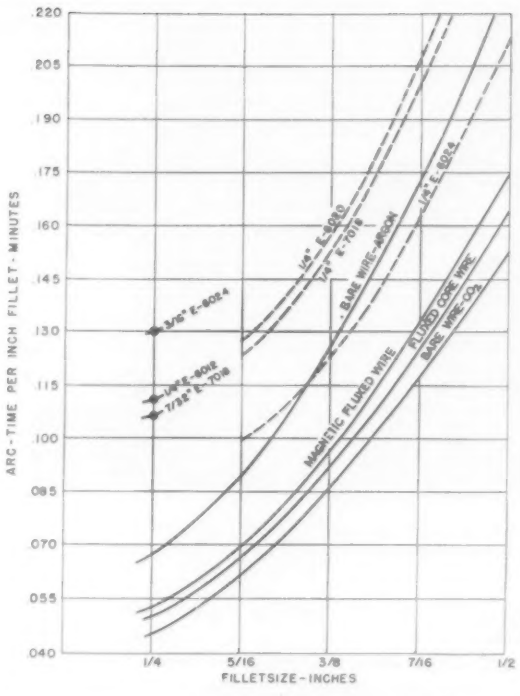


Fig. 2—Comparison of fillet-welding arc time for the gas metal-arc processes and covered electrodes

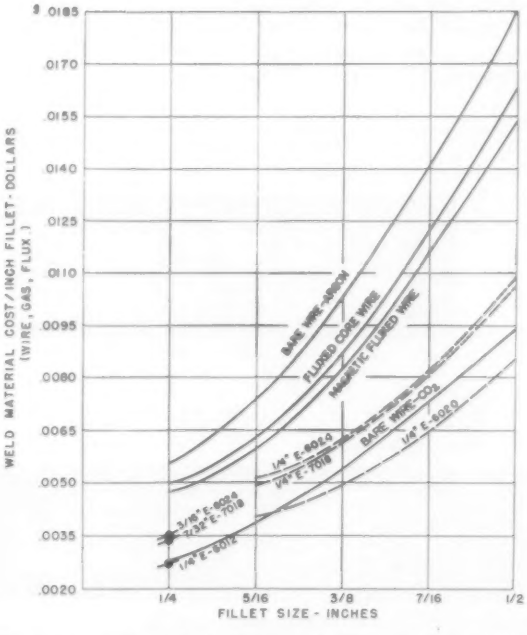


Fig. 3—Comparison of selected costs for fillet welding with the gas metal-arc processes and covered electrodes

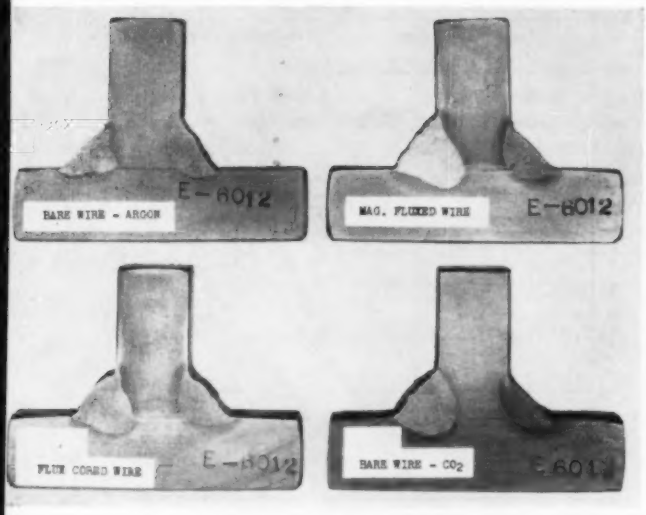


Fig. 4—Typical fillet-weld penetration obtained with the gas metal-arc processes and covered electrodes

manual metal-arc welding using covered electrodes.

It is traditionally assumed in manual fillet welding that weld fusion extends only to the intersection of the members forming the joint. The strength is based on a throat dimension. With the CO_2 metal-arc welding processes, the weld fusion does not stop at the joint intersection but definitely extends into the base plates. This fillet root penetration provides a considerable safety factor and/or a significant increase in joint strength. If industry is to realize maximum economic benefit from these new semiautomatic and automatic welding processes, this increased strength must be recognized and incorporated into the weld design and specifications.

An investigation was conducted to develop data for the manually operated, semiautomatic, CO_2 metal-arc processes which takes into account this increase in penetration. The comparative penetration is illustrated in Fig. 4. The scope of this investigation included the use of three types of CO_2 metal-arc welding processess and three types of standard arc-welding, covered electrodes, namely:

CO_2 metal-arc processes	Covered electrodes
Flux-cored wire	E-7018
Magnetic-fluxed wire	E-7024
Bare wire–CO_2	E-6012

Testing Procedure

General. There are three major factors to consider in determining the effective penetration of a welding process, namely: (1) plate thickness, (2) travel speed, (3) current or wire-feed setting.

The comparative weld penetration of the various processess was determined using fillet "T" joints and bead-on-plate test specimens. The material used for all specimens was mild steel, 1/4 to 3/4-in. thick.

The welding conditions were chosen from previously established production and laboratory experience and are representative of the normal operation of each process or electrode. Those used in establishing the penetration values for the CO_2 processes and standard arc-welding electrodes are shown in Table 2.

Bead-on-plate Tests. The variation of weld penetration between the CO_2 processes and arc-welding covered electrodes are shown in Table 3. The penetration measurements were made with a planimeter on magnified photographs of the weld cross sections similar to Fig. 5.

An analysis of the factors affecting fillet-weld

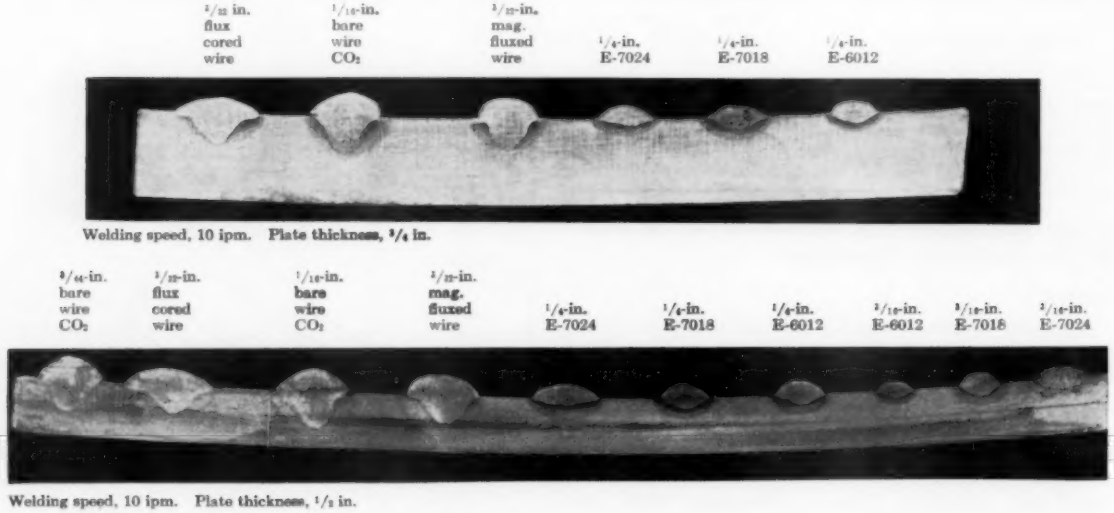


Fig. 5—Comparison of weld penetration on 1/2- and 3/4-in. plate using the CO_2 processes and covered electrodes

Table 2—Welding Conditions Used in the Fillet-weld Penetration Tests

Process or electrode	Welding wires or electrode diam, in.	Welding current, amp	Wire feed speed, ipm	Plate thickness, in.	Range of travel speeds, ipm
Magnetic-fluxed wire	3/32	460	115	1/4-1/2-3/4	10 to 20
Flux-cored wire	3/32	470	168	1/4-1/2-3/4	10 to 30
Bare wire–CO_2	3/64	360	600	1/4-1/2-3/4	10 to 50
E-7018	5/16	265	11.0	1/4-1/2-3/4	5 to 20
	1/4	330	9.0		
E-7024	5/16	270	13.0	1/4-1/2-3/4	5 to 20
	1/4	340	9.5		
E-6012	5/16	185	10.0	1/4-1/2	5 to 20
	1/4	315	9.0	1/4-1/2-3/4	

Table 3—Depth of Weld Penetration Obtained in Bead-on-plate Tests

A. Depth of weld penetration (in.), 1/4-in. plate

Welding speed, ipm	Process or electrode: Bare wire–CO_2[a]	Flux-cored wire–CO_2[b]	Magnetic fluxed wire–CO_2[b]	E-7024, 5/16 in. diam	E-7018, 5/16 in. diam	E-6012, 1/4 in. diam
10	...	...	...	0.09	0.09	0.10
20	...	0.19	...	0.09	0.09	0.08
30	0.21	0.16	0.21	...	...	...
40	0.17	0.15	0.18	...	...	...
50	0.15	0.14	...	...	...	...

B. Depth of weld penetration (in.), 1/2-in. plate

Welding speed, ipm	Process or electrode: Bare wire–CO_2[a]	Flux-cored wire–CO_2[b]	Magnetic fluxed wire–CO_2[b]	E-7024: 5/16 in. diam	E-7024: 1/4 in. diam	E-7018: 5/16 in. diam	E-7018: 1/4 in. diam	E-6012: 5/16 in. diam	E-6012: 1/4 in. diam
10	0.29	0.25	0.28	0.09	0.08	0.09	0.10	0.06	0.08
20	0.25	0.22	0.25	0.09	0.08	0.09	0.09	0.06	0.08
30	0.22	0.17	0.20	...	0.06	...	...	...	...
40	0.17	0.15	...	...	...	...	...	...	...

C. Depth of weld penetration (in.), 3/4-in. plate

Welding speed, ipm	Process or electrode: Bare wire–CO_2[a]	Flux-cored wire–CO_2[b]	Magnetic-fluxed wire–CO_2[b]	E-7024, 1/4 in. diam	E-7018, 1/4 in. diam	E-6012, 1/4 in. diam
10	0.28	0.25	0.29	0.06	0.09	0.07
20	0.25	0.22	0.26	0.06	0.08	0.06
30	0.20	0.18	0.23	0.03	...	...
40	0.19	0.15	...	...	...	...

Note: [a] 3/64" diam welding wire. [b] 3/32" diam welding wire.

penetration as obtained from the data determined from bead-on-plate and fillet-weld test is shown in Fig. 6. The depth of weld penetration is shown for three plate thicknesses (1/4, 1/2, 3/4 in.) at various welding speeds. There are two trends noted:

1. Penetration decreases with an increase in plate thickness. This trend, for all practical purposes, was not significant for covered electrodes, and was only slight for the CO_2 processes.

2. The depth of weld penetration decreases with an increase in the welding speed for both the CO_2 processes and covered electrodes.

The greatest influence on the depth of weld penetration that was obtained for the CO_2 processes resulted from the change in welding speeds (Table 3). On 3/4-in. plate, the depth of weld penetration decreased from 0.25 to 0.18 in. with a change in welding speed from 10 to 30 ipm. On 1/2-in. plate, the depth of weld penetration decreased from 0.28 to 0.15 in.

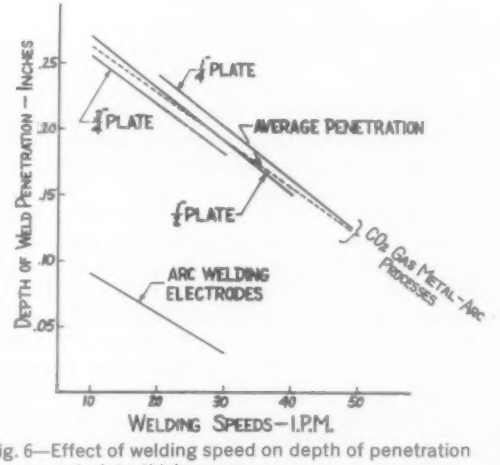
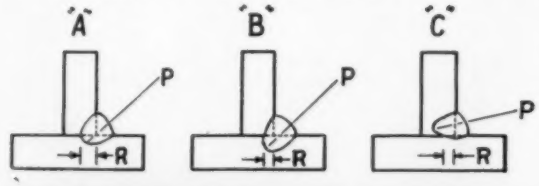
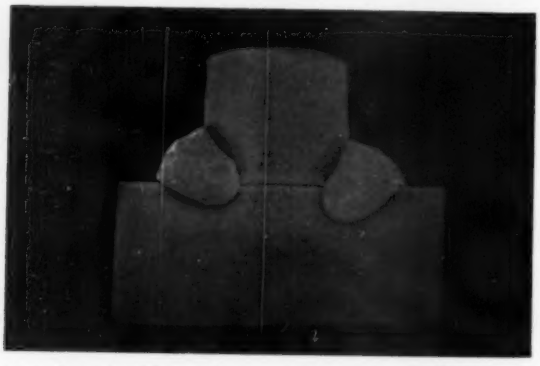


Fig. 6—Effect of welding speed on depth of penetration for several plate thicknesses

R = Root penetration. P = Position of electrode





$^3/_{32}$-in. bare wire, CO_2. Welding speed, 20 ipm. Plate thickness, $^3/_4$ in.

Fig. 7—Effect of electrode positioning on fillet-weld penetration

Weld penetration obtained with the CO_2 processes

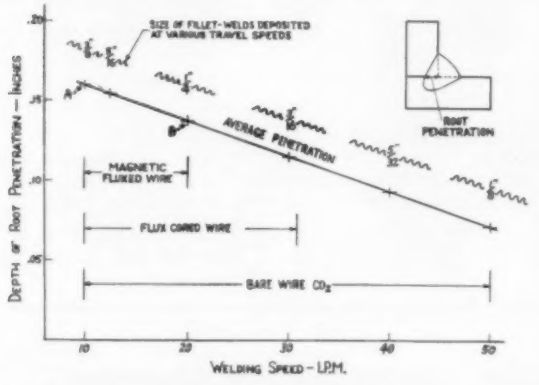


Fig. 8—The averate root penetration found for fillet welds using the CO_2 processes

with a change in welding speed from 10 to 40 in. On $^1/_4$-in. plate, the depth of weld penetration decreased from 0.24 to 0.125 in. with a change in welding speed from 20 to 50 ipm.

The depth of fillet-weld penetration with covered electrodes decreased from 0.09 to 0.03 in. with a change of welding speed from 10 to 30 ipm. As a result of the very small change in the depth of weld penetration that occurred due to the change in plate thickness (from $^1/_4$ to $^3/_4$ in.), an average curve was plotted for the three CO_2 curves. The averaged values were used in determining the equivalent fillet sizes for the CO_2 processes and covered electrodes.

Fillet-weld Tests. Fillet-weld tests were carried out to confirm the weld penetration values found using the bead-on-plate tests. The results of the fillet tests showed that the penetration values were within 5% of the values obtained with the bead-on-plate tests.

It was found that the positioning of the electrode in the joint by the operator had no effect on the depth of weld penetration. However, it did have an important effect on the actual root penetration. This is illustrated in Fig. 7 (top). The effect of improper positioning of the electrode in joints "B" and "C" may cause a 25 to 40% reduction in the weld strength. The reduction in joint strength was determined from fillet-weld break tests carried out when using both proper and improper electrode positioning with the CO_2 processes.

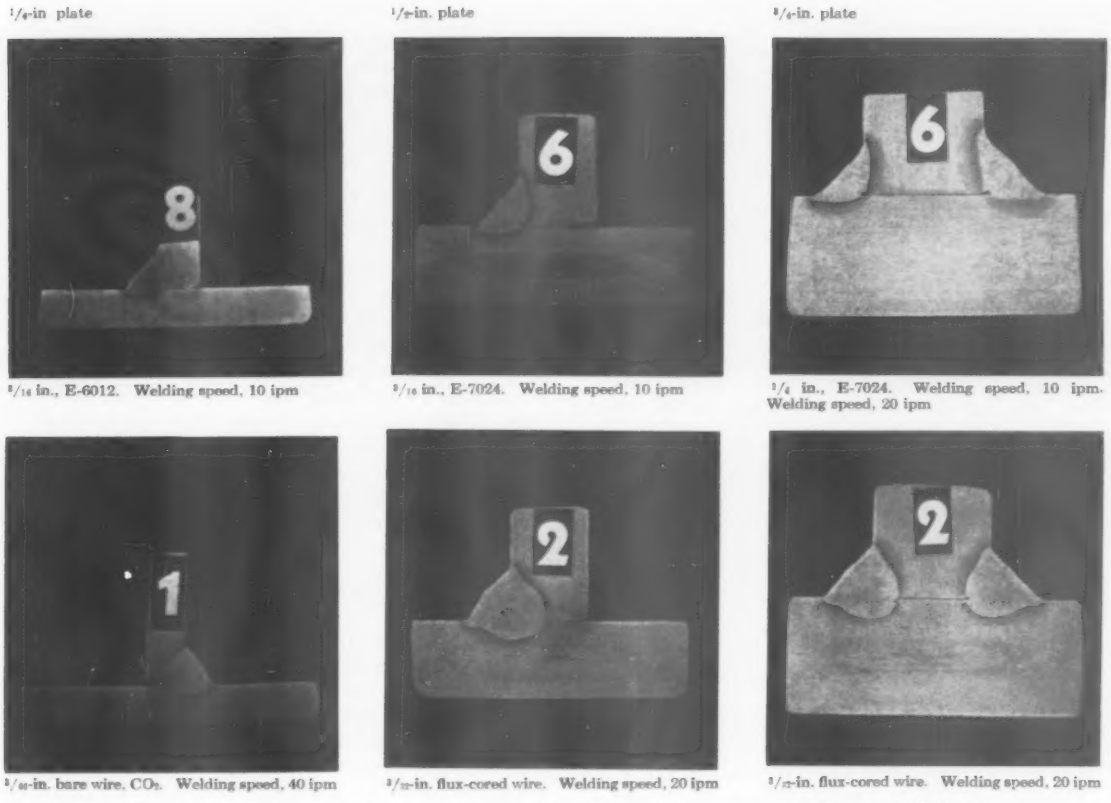
Figure 7 (bottom) shows two fillet-welds made on $^3/_4$-in. plate with the CO_2 process at the same welding speed and current settings. On the left side of the joint, the electrode was positioned properly to obtain the greatest fillet throat with equal penetration in both legs. On the right side, the electrode was positioned improperly resulting in unequal leg penetration and a reduction in the actual root penetration and the fillet-weld throat.

The average depth of fillet-weld penetration obtained for the CO_2 process, shown in Fig. 6, was reduced 40% to allow for the maximum variation that may occur in the root penetration due to the normally expected changes in the positioning of the electrode in the joint by the operator. The reduced average fillet-weld root-penetration curve is depicted in Fig. 8. This very conservative average depth of fillet-root penetration would normally give an added safety factor to the welds produced with the CO_2 processes.

The range of fillet welds deposited at the various welding speeds with the CO_2 processes are also shown in Fig. 8. That is, for a welding speed of 10 ipm, the magnetic-fluxed wire, flux-cored wire and bare wire–CO_2 process will deposit a $^3/_8$-in. fillet-weld with a 0.17-in. depth of root penetration (point A). Similarly, at 20-ipm weld speed, the three processes will deposit a $^1/_4$-in. fillet weld with a root penetration of 0.14 in. (point B).

The bracket lines under the average penetration curve indicate the general range of single-pass fillet welds which are practical to deposit by the indicated process under the welding conditions used in these tests. The magnetic-flux process has an approximate minimum fillet size of $^1/_4$ in. when using a $^3/_{32}$-in. welding wire. The flux-cored wire process has a minimum fillet size of $^3/_{16}$ in. when using $^3/_{32}$-in. welding wire. The bare wire–CO_2 process can deposit a $^1/_8$-in. fillet-weld when using $^3/_{64}$-in. diam welding wire. This is, however, very difficult to do manually because of the high travel speeds required, unless the newer power supplies containing reactors in the electrical circuit are used.

A comparison of the fillet-weld penetration for the CO_2 processes and the manual covered electrodes is shown in Fig. 9. Figure 9 (left) shows some typical



3/16 in., E-6012. Welding speed, 10 ipm

3/16 in., E-7024. Welding speed, 10 ipm

1/4 in., E-7024. Welding speed, 10 ipm. Welding speed, 20 ipm

3/32-in. bare wire, CO_2. Welding speed, 40 ipm

3/32-in. flux-cored wire. Welding speed, 20 ipm

1/16-in. flux-cored wire. Welding speed, 20 ipm

Fig. 9—Typical fillet-weld penetration on 1/4", 1/2", and 3/4-in. plate using the CO_2 processes and covered electrodes

fillet-weld cross sections made on 1/4-in. plate. The average fillet-root penetration for the CO_2 process at 40-ipm welding speed was 0.17 in. For 3/16-in. diam E-6012 electrodes, the average fillet-root penetration at 10-ipm welding speed was 0.03 in. Figure 9 (center) shows typical fillet-weld cross sections made on 1/2-in. plate. The average fillet-root penetration is 0.22 in. at 20-ipm welding speed, for the CO_2 processes, as compared to 0.09 in. at 10-ipm welding speed for 3/16-in. E-7024 electrodes. Figure 9 (right) shows typical fillet-weld cross sections made on 3/4-in. plate. The average fillet-root penetration is 0.22 in. at 20-ipm weld speed for the CO_2 processes. For 1/4-in. E-7024 electrodes, the average fillet-root penetration is 0.07 in. at 10- and 20-ipm welding speed.

A curve was plotted using the data given in Fig. 8 to show the total fillet throat that is obtained with the CO_2 processes. The total fillet-throat dimension was found by combining the throat dimensions for each fillet size with the amount of root penetration obtained at each welding speed. The sketch in Fig. 10 illustrates where the combined fillet-throat dimension is measured for both CO_2 welding and for covered electrodes.

The strength of a fillet weld is dependent upon three factors:

1. Strength of weld metal deposited.

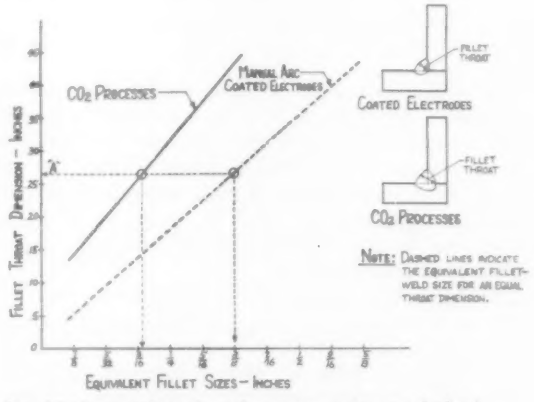

CO2 Processes
Manual Arc Coated Electrodes
Fillet Throat Dimension – Inches
Equivalent Fillet Sizes – Inches
Coated Electrodes
Fillet Throat
CO2 Processes
Fillet Throat
Note: Dashed lines indicate the equivalent fillet-weld size for an equal throat dimension.

Fig. 10—Conversion chart for determining equivalent fillet sizes for the CO_2 processes and covered electrodes

2. Method of stressing.
3. Throat dimension.

Previous tests have shown that the weld metal deposited using the CO_2 metal-arc processes has physical properties equal to or greater than the E-70XX type covered electrodes. For comparison purposes, the method of stressing could be considered constant for both methods. The one remaining factor is the fillet-throat dimension, which, in this

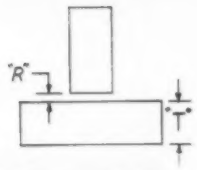
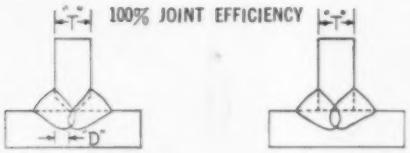


Plate thickness "T," in.	Suggested max gap opening "R," in.	Fillet size, in.
1/8	1/16	1/8
3/16	3/32	3/16
3/8	1/8	1/4
1/2	1/8	3/8
5/8	5/32	3/8
3/4	5/32	7/16

Fig. 11—Control limits on gap opening for fillet-welds made with the gas metal-arc processes. (Approximate; may vary somewhat based on CO_2-gas-shielded process involved)



Material thickness, in.	Covered electrode		CO_2-Shielded processes	
	Double fillet size, in.	Depth of bevel "D," in.	Double fillet size, in.	Depth of bevel "D," in.
3/8	3/8	None	1/4	None
1/2	1/4	3/16	5/16	None
5/8	5/16	1/4	3/8	None
3/4	3/8	1/4	3/8	1/8

Fig. 12—Fillet-weld design data based on the penetration factor obtained for the CO_2 processes

case, will produce a difference in the fillet-weld strength. Fillet welds having equivalent strength will therefore have equal fillet throats. An example of equivalent fillet throats is shown in Fig. 10. A 3/8-in. fillet weld deposited with covered electrodes has a throat dimension of 0.27 in. (point A); the CO_2 fillet weld having the same throat dimension would fall between 3/16 and 1/4 in.

By following this procedure, a coversion chart of equivalent-size fillet welds was established for the CO_2 processes and covered electrodes (E-70XX); it is shown in Table 4. Design information in the form of allowable loads per lineal inch of fillet weld was developed by applying the equivalent fillet size data to allowable load data for E-70XX fillet welds as calculated using shear-stress formulas. The potential economy that exists in using the data in Table 4 on production applications is quite apparent.

Fillet and Groove Design Data

Fillet-weld Joints

Increased penetration in fillet welds, if used properly, can be of great economic value when applying the gas metal-arc processes. It can also cause considerable trouble if misapplied. The current densities of the gas metal-arc processes may vary from 95,000 to 200,000 amp/sq in. This is considerably higher than that used with covered electrodes. It is readily seen why burn-through problems become acute when fit-up is allowed to vary greatly. Figure 11 shows the suggested maximum root or gap opening for fillet welds. Such fit-up tolerances puts a definite limitation on the potential use of CO_2 welding. However, these tolerances can be liberalized somewhat in light of more recent development in power sources, especially for the thinner materials. This does not completely alleviate the fact that joint fit-up is still a matter to be concerned with.

Figure 12 illustrates how the penetration factor can affect joint efficiency and joint preparation on double-bevel fillet welds. The joint preparation and weld-metal requirements will be considerably less for the CO_2 processes as compared to covered electrodes and yet the joint strength will be equal.

Groove Joints

The penetration of gas metal-arc welding, particularly where CO_2 is used as the shielding gas, allows a smaller groove angle and groove depth to be used and still maintain the same joint penetration.

The proper utilization of this penetration characteristic can result in lower weld-metal requirements and increased production rates. A further increase in production rates is obtained from the high weld-metal deposition rates of the gas metal-arc processes.

Table 4—Comparative Fillet-weld Strength Obtained with the CO_2 Processes and Covered Electrodes

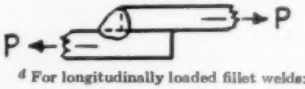
—Equivalent fillet size, in.—		Allowable load, lbs/lineal in.	
Covered E-70XX electrodes, (L_1)[a]	CO_2 welding processes[b]	Transverse load[c]	Longitudinal load[d]
3/16	1/8	2757	2179
1/4	5/32	3675	2975
5/16	3/16	4594	3633
3/8	1/4	5512	4359
1/2	5/16	7349	5810
5/8	3/8	9188	7264

[a] Working stress in shear for weld metal having a 57,000-psi yield strength (min), i.e., E-70XX.

$$(S)_w = \frac{\text{shear yield point}}{\text{factor of safety}} = \frac{\text{yield point} \times 0.577}{\text{F.S.}} = \frac{57{,}000 \times 0.577}{2} = 16{,}400 \text{ psi}$$

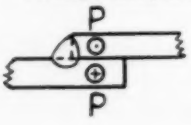
[b] Weld metal physical properties equivalent to E-70XX electrodes.

[c] For transversely loaded fillet welds:



P, lb = $(S_2)_w$ $(L_1/1.118)$

[d] For longitudinally loaded fillet welds:



P, lb = $(S_2)_w$ $(L_1/1.414)$

(100% JOINT PENETRATION)

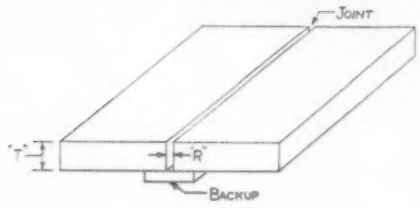


Plate thickness "T," in.	Root opening "R," in.	
	Covered electrode	CO_2-shielded processes
3/16–1/4	"T," min.	0–1/8 in.
1/4–1/2	Not recommended	0–1/8 in.

Fig. 13—Square-groove joints for gas metal-arc processes and covered electrodes

(100% JOINT PENETRATION)

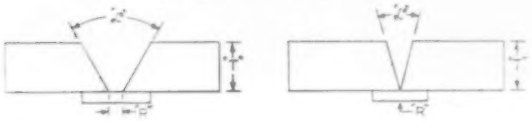


Plate thickness "T," in.	Covered electrodes		CO_2-shielded processes	
	Included angle, deg, "α"	Root opening "R," in.	Included angle, deg, "α"	Root opening "R," in.
3/8–1/2	45–60	1/4	25	0
1/2–3/4	60–90	1/4	30	1/8

Fig. 14—Single-vee groove joint for gas metal-arc processes and covered electrodes

Figures 13 through 16 illustrate recommended groove designs for CO_2 metal-arc welding which are modifications of those specified in the AWS recommended practices for covered electrodes.

Figure 17 illustrates how the CO_2 gas metal-arc processes may be applied more efficiently on special joints by changing to a joint design which will utilize their deep-penetration characteristics and reduce the volume of weld metal required and still develop the same joint strength.

Conclusions

Higher deposition rates are characteristic of all the gas metal-arc welding processes, especially those where CO_2 is used as the shielding gas. Joints, fixtures, etc., must be designed so that the higher welding rate can be used. The welding operator must be able to weld at the speeds normally obtainable without excessive fatigue. In many instances automatic welding is the only way that maximum welding speeds can be used.

The principal disadvantage of the processes, their tendency to burn through on joints having poor fit-up, must be kept in mind.

The increased penetration of the gas metal-arc processes should be exploited. In groove welds, smaller groove angles and groove depths should be used. In fillet welding smaller fillet sizes should be specified, relying on joint penetration to contribute to joint strength. Both of these steps will lead to use of less weld metal per foot of joint and lower cost beyond that which is obtainable from increased welding deposition rate alone.

(WELDED FROM ONE SIDE WITH INCOMPLETE JOINT PENETRATION)

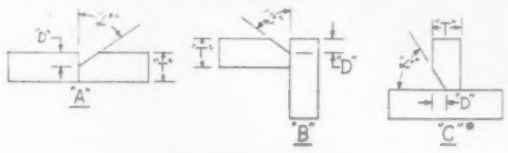


Plate thickness "T," in.	Covered electrodes		CO_2-shieldedprocesses	
	Bevel angle, deg, "α"	Depth of bevel "D," in.	Bevel angle, deg, "α"	Depth of bevel "D," in.
3/8	45–60	1/4	15–20	1/8
1/2	45–60	1/4	15–20	1/8
5/8	45–60	5/16	15–20	1/8
3/4	45–60	1/2	15–20	3/16

Note: Equivalent joint efficiency is provided by the CO_2-shielded processes on Joint C without bevel.

Fig. 15—Single-bevel groove joints for gas metal-arc processes and covered electrodes

(100% JOINT EFFICIENCY)

Covered electrodes CO_2-shielded processeses

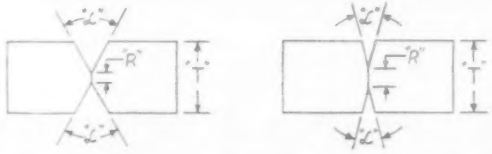
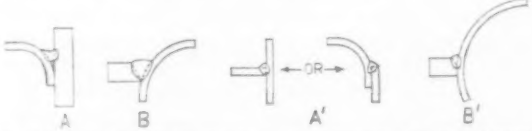


Plate thickness "T," in.	Covered electrodes		CO_2-shielded processes	
	Bevel angle, deg., α°	Land "R," in.	Bevel angle, deg, α°	Land "R," in.
5/8	60–90	1/8	30	5/16
3/4	60–90	1/8	30	1/4
1	60–90	1/8	30	1/4

Fig. 16—Double-vee groove joints for gas metal-arc processes and covered electrodes



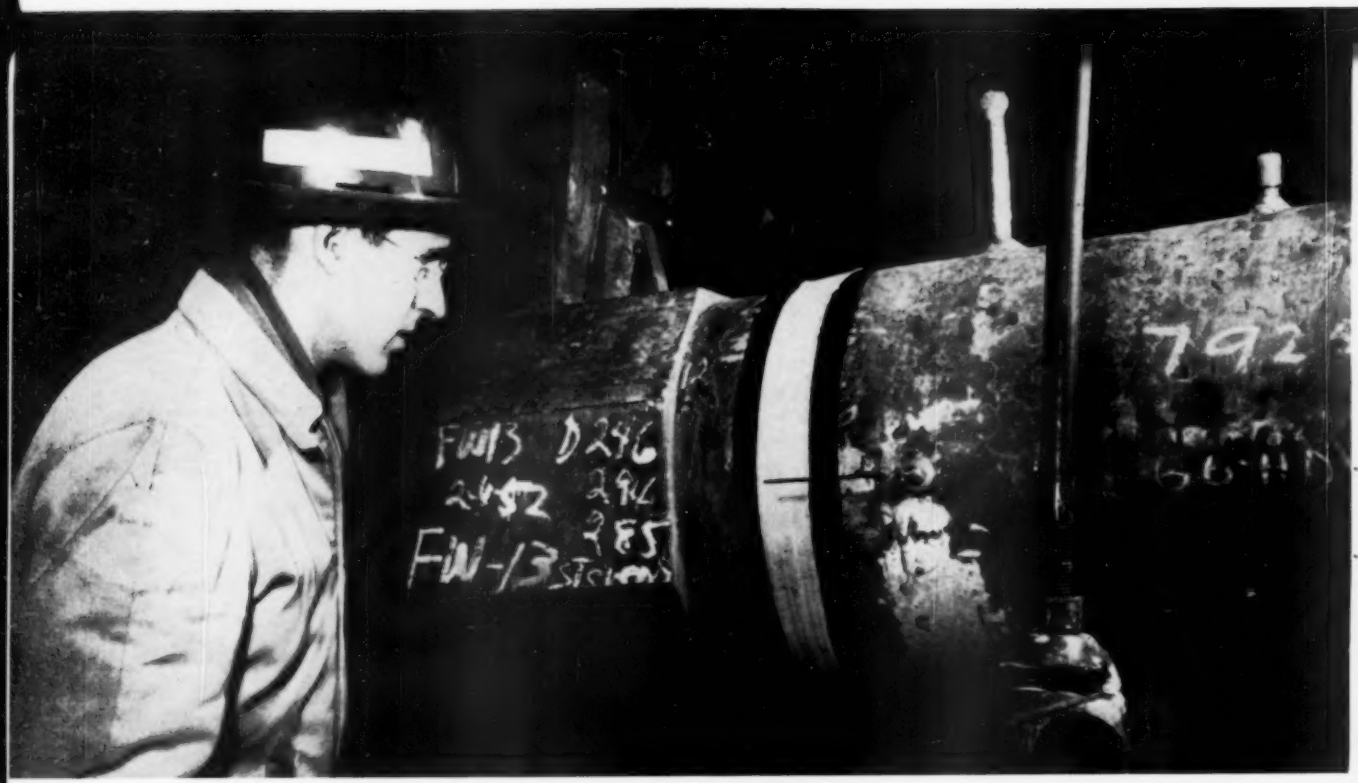
Good for covered electrode or submerged-arc process (A & B)

1. Provides proper penetration in joint by groove opening.
2. Additional forming and material used in the joint.
3. Larger amount of weld metal required.

Recommended for CO_2-shielded processes (A' & B')

1. Utilizes penetration provided by the welding procedure.
2. More economical weld-joint design.
3. Reduced volume of weld metal in the joint allows higher welding speeds.

Fig. 17—Design modifications on special joints (rolled flange to pipes, bushings and plates) for gas metal-arc welding processes



Radiographic inspection of butt weld with fixture inserted in the pipe through access hole

Service Failures of Pipe Weldments

are often the result of defects not detected by customary inspection techniques

BY HELMUT THIELSCH

The ASME Boiler and Pressure Vessel Code and the ASA Code for Pressure Piping have been prepared and revised by various committees composed of the foremost engineering and fabrication authorities. On the basis of their extensive experience and thinking, the various Code rules have been formulated "to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long safe period of usefulness."* The Code rules encompass requirements governing design, limitations on the use of materials, fabrication and welding procedures and inspection during and after fabrication.

In formulating the Code rules, the various committees attempt to consider carefully the opinions and needs of users, fabricators, steel producers and inspectors. Nevertheless, as in any committee activity, compromises must, at times, be made. The users of fabricated piping obviously would desire the most stringent inspection rules to insure as "perfect" a fabricated product as possible. On the other hand, no "perfect" product such as steel is made. The inspection requirements, therefore, must be based on realistic considerations. For example, in butt welds, slight amounts of porosity and slag are considered acceptable by various codes. Within the limitations established in the respective codes, they are not considered in any way detrimental to the joint quality and efficiency.

The additional or more-stringent inspection requirements desired by many users may also increase considerably the final cost of the fabrication. Some of the special tests desired by users may provide data unrelated to the service characteristics and "level of safety" of the final fabrication. For example, some of the acceptance standards arbitrarily selected for test results obtained by ultrasonic inspection have caused some users to reject pipe. The steel producers on the other hand, have not accepted pipe rejected by fabricators or

HELMUT THIELSCH is Metallurgical Engineer, Industrial Piping Laboratory, Grinnell Co., Providence, R. I.

* From the Foreword of ASME Boiler and Pressure Vessel Code, Section I, 1959 Edition.

users on the basis of ultrasonic inspection. Where the pipe rejected by the user was subsequently sectioned and tested by destructive tests and found to be in accordance with respective ASTM material specifications, the fabricator involved frequently has had to replace the pipe at his own expense.

It must be recognized that each specific destructive test or nondestructive test will evaluate a *particular* material in comparison with another material tested under the *same* testing conditions. The interpretation of the test results and their correlation to the actual service characteristics, at best, are only approximate. Quite frequently they may bear little or no relation to the actual service performance of the material or weldment.

Destructive or nondestructive tests and inspection procedures also may not reveal some inherent weaknesses or certain types of defects in a steel material which, nevertheless, may seriously impair the service life of the fabricated weldment. For example, the results of extensive small-section creep tests conducted at elevated temperatures on Type 347 stainless-steel specimens led to the assumption that this grade was one of the best grades available for service at temperatures of 1050 to 1100° F or even higher. Use of this grade of steel in steam-power piping, however, revealed serious cracking tendency in the base-metal heat-affected zone adjacent to the weld.[1]

Laboratory test data are also frequently used to serve as bases for the specification of fabrication procedures. However, before such a method is followed, committees or engineers specifying such procedures should evaluate the effects of shop fabrication or field-erecting conditions. Creep tests conducted on small laboratory specimens, for example, have shown that chromium-molybdenum steel normalized at 1650° F, and tempered at 1250° F shows better resistance to creep than hot-worked steel which has been tempered only.

Under shop conditions where a number of pipe sections are heat treated at the same time, the uniformity in heat treatment obtained in a laboratory furnace is not realized. Temperature gradients are likely to exist in the large furnaces necessary to handle production schedules. Moreover, when the movable car bottom is pulled out of the furnace after the 1650° F normalizing heat treatment and the pipe is permitted to air cool, the pipe sections at the top will naturally cool most rapidly. The piping at the bottom of the car, on top of the heat-retaining brick lining, will cool more slowly. As a result, considerable differences can be obtained in the metallurgical structures of the piping at the top and bottom of the same furnace charge.

In a commercial shipment of 1¼% Cr – ½% Mo piping furnished in the normalized and tempered condition by one of the major producers of piping for critical steam-power-plant service, the microstructures shown in Fig. 1 represented two pipe sections from the same original heat of steel (melt) which were normalized and tempered in the same heat-treating charge. To a metallurgist, the difference in the microstructures of the two pipe sections is considerable. Significant differences in the creep properties of small test specimens removed from the two pipe sections could also be expected. Nevertheless, under service conditions in the power plant involving steam at 1000° F and 1500-psi pressure, both pipe sections are likely to behave in a completely satisfactory manner in the piping system designed in accordance with the "S" values of the ASME Boiler and Pressure Vessel Code. As long as the service conditions for which the piping was designed are not altered, both materials should give entirely satisfactory service.

It must be realized, also, that large pipe sections removed from a furnace for the air cool after the normalizing heat treatment of 1650° F may distort somewhat because of one side being cooled more rapidly than the other. Welding or other local hot

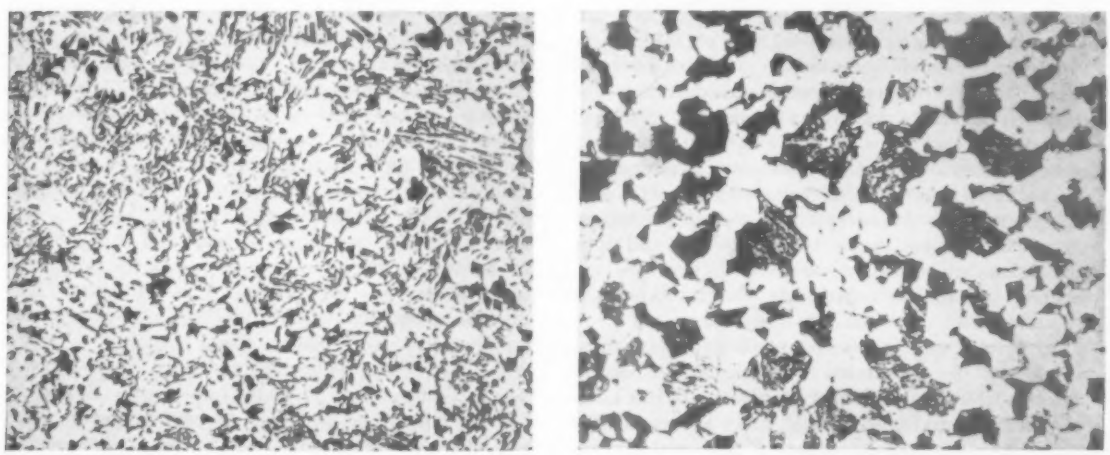


Fig. 1—Microstructures of 1¼% Cr — ½% Mo steel pipe from the same melt and normalized and tempered in the same heat-treating furnace charge. X 100

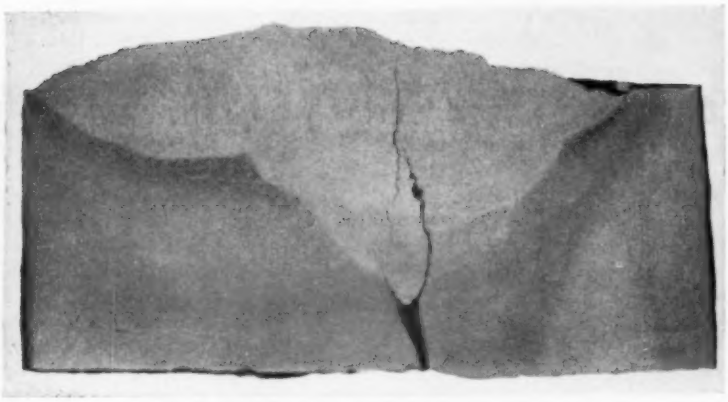
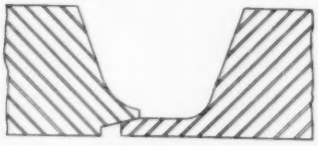


Fig. 2—Failure in pipe joint caused by stress-corrosion cracking in "lack-of-penetration" zone in root of pipe weld. X 3

Fig. 3—Overlap-type root preparation occasionally used in pipe butt joints to eliminate backing rings



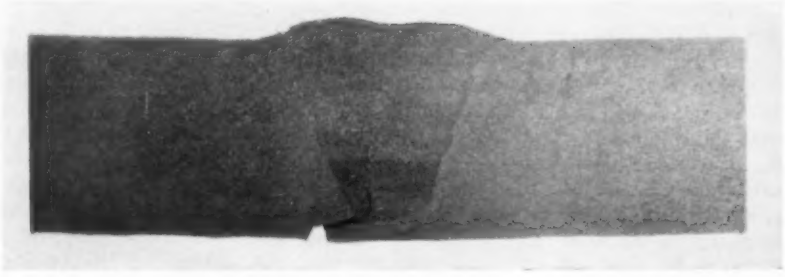


Fig. 4—Cracking starting from lack of fusion in root of weld in pipe butt joint with overlap root preparation

fabricating operations may also cause distortion. Straightening of the pipe sections in the mill or fabricating shop is done by heating the pipe locally with gas burners to "orange heat" (1600–1900° F) and pulling the sections back into shape. Certainly, this procedure removes in the areas heated whatever effects the normalizing heat treatment might have had. This practice has been performed extensively on carbon and low-alloy steels and has not resulted in an epidemic of failures. In fact, there is no record of any piping failure which can be ascribed to this practice.

Many other examples could be given to illustrate that laboratory test results and considerations are frequently overemphasized by engineers preparing specifications and codes, and may have no bearing on the actual service life of the fabricated weldment.

Laboratory research and test programs are very important to the advancement of our technological age but, to be of real value, the conclusions and their applications must be consistent with practical experience and actual fabricating conditions in the shop and field.

The testing and inspection techniques developed to evaluate the soundness of fabricated structures have contributed significantly to the use of engineering materials under more and more severe service conditions. The development of new and the refinement of existing testing and inspection facilities are also giving operating engineers increasing comfort and assurance in the level of safety of the systems for which they are responsible. Engineers are obviously concerned since, at the increasingly severe operating pressure and temperatures involved, service failures can become extremely hazardous and costly.

Unfortunately, a false sense of security can be obtained where a fabricated system has been thoroughly inspected with the latest techniques and where no defects have been detected. Many potentially dangerous conditions can defy some or all of the standard testing or inspection equipment available. Many such conditions exist now in our critical systems, and may not be detected until sudden rupture occurs in the materials involved. The average failure in high-temperature high-pressure steam piping requires about 5 to 10 yr to develop and propagate across the pipe-wall thickness. To date, the majority of failures in steam power plants have occurred in carbon-steel and carbon-molybdenum steel weldments which by now have been in service for fifteen or more years. The chromium-molybdenum and stainless-steel materials have experienced fewer failures to date. Moreover, these materials generally have been in service only about five to ten years. Since the service conditions involved in piping systems employing chromium-molybdenum and stainless-steel materials are more severe than those in piping of carbon and carbon-molybdenum steels, concern

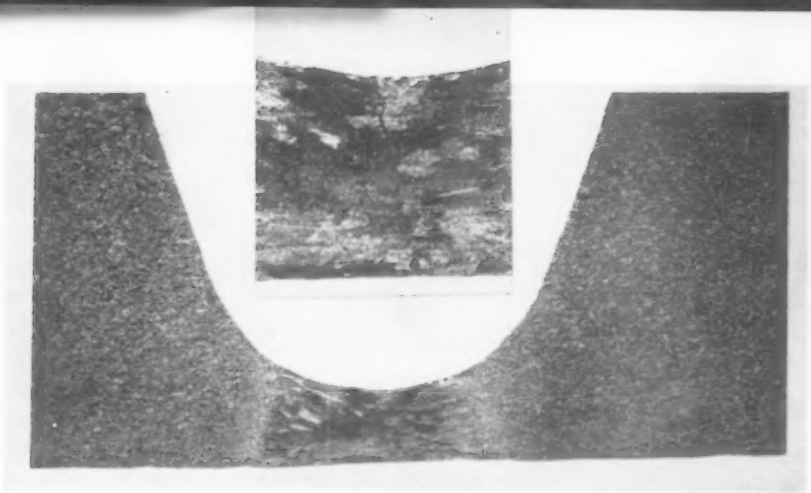


Fig. 5—Example of centerline crack in weld deposit not detected by X-ray radiographic inspection. X 5. (X 12 for inset)

obviously is required. As a result of numerous "near-failures" detected in routine inspection programs, there appears to be no basis for a greater confidence in the level of safety in chromium-molybdenum and stainless-steel weldments than in those of lower-alloy content.

It must also be recognized that many actual or near failures are never publicized in order not to concern operating personnel or involve the companies concerned with unfavorable publicity. Exceptions are where service failures result in loss of life.

To illustrate the danger of a false sense of security where materials have been purchased to all of the requirements of applicable ASTM specifications and have been welded and inspected to the requirements of the ASME Boiler and Pressure Vessel Code and other similar codes, a few typical examples of actual or developing service failures and their causes will be illustrated.

Design

It must be remembered that weld failures are of primary interest here. Not considered will be failures which, though they occurred in or through welds, have been primarily the result of improper design causing excessive stress concentrations.

The design of the pipe-joint bevel preparation can have a significant bearing upon the soundness of the finished joint.

The easiest and most economical pipe-joint preparation would involve butting together two pipe ends with V-bevel preparations and welding the joint by shielded metal-arc welding with covered electrodes. However, shielded metal-arc welding of the V-bevel joint design may leave "lack-of-penetration" areas at the root of the weld. These are considered extremely undesirable for services involving subzero temperatures, high temperatures or pressures, thermal or mechanical fatigue, or stress corrosion, and are not acceptable in piping fabricated and inspected under the ASME Boiler and Pressure Vessel Code and many other codes. To insure full-penetration welds, joint designs are frequently specified which employ backing rings to "back up" the root of the joint when welding with the shielded metal-arc process, unless the root of the pipe joint is made by inert-gas tungsten-arc welding.

For service applications not considered "extremely" severe and where the ASME Boiler and Pressure Vessel requirements do not apply, the use of backing rings may be omitted. Such piping, when it contains "lack-of-penetration" areas at the root of the weld, may nevertheless fail even though the service is not considered critical. Figure 2 illustrates a weld failure in boiler-feed water piping in a small power plant, caused by stress corrosion.[2] All but 2 in. of the joint exhibited full penetration along the weld circumference at the inside of the pipe. Nevertheless, the 2-in. long "lack-of-penetration" notch was sufficient to permit stress-corrosion cracking. Radiographic examination would have detected the "lack-of-penetration" area, but was not done since it was not required under the Code for the service involved.

Where quality welds are required, the joint design specified should be one which makes the welding task as easy as possible for the welder. The weldability characteristics of the base material and the welding process used should also be considered. Weld-joint designs which make electrode manipulation and observation difficult obviously are more susceptible to defects than those which are more accessible.

Special bevel preparations, such as the one shown in Fig. 3, represented an early attempt to eliminate backing rings. However, in field welding in awkward locations, it is a somewhat greater problem for the welder to fuse properly into the zone formed between the two pipe edges. Where proper fusion is not obtained, a notch will be retained. During subsequent service this notch may lead to cracking, as shown in Fig. 4.

Since the most stringent inspection with all available techniques is nevertheless not a guarantee that the weld joint is completely sound, the importance of selecting the joint preparation most advantageous for the welder and material involved cannot be over-emphasized. For example, inert-gas tungsten-arc welding is being applied increasingly to pipe welding, particularly where full-penetration welds without backing rings are desired.[3] Unfortunately, some of the fine cracks which may result in the root pass are not always detected by radiographic, dye-penetrant or magnetic-particle inspection techniques. Figure 5 illustrates the cross section of a weld containing a center line crack which was not

Fig. 6—Crack in root pass in 1¼% Cr–½% Mo pipe butt weld made by inert-gas tungsten - arc welding. Crack does not penetrate through thickness of root weld deposit. X 5

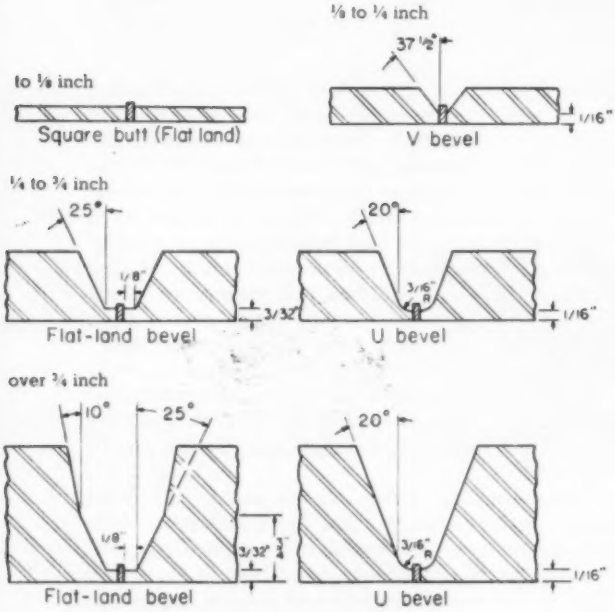


Fig. 7—Joint preparations recommended for inert-gas tungsten-arc root-pass welding of piping

detected by radiographic-inspection techniques. Only deep etching of a cross section containing the tightly closed crack revealed its presence. Sometimes a crack does not even penetrate the full thickness of the root pass (see Fig. 6) and, consequently, cannot be detected by dye-penetrant or magnetic-particle inspection.

The joint designs which minimize the root-pass cracking tendency employ the "flat-land" and "U" bevel preparation illustrated in Fig. 7. Consumable insert rings are also beneficial in further insuring weld-root soundness.[3-5] Since inspection techniques do not necessarily guarantee weld soundness, these somewhat more-costly methods may be preferred over the 37½-deg V-bevel normally recommended in the ASA Code for Pressure Piping for shielded metal-arc welding and furnished on standard fittings.

Material Selection, Specification and Handling

Electrode Composition

About twenty years ago, welders had little concern about the particular steel electrodes used. One steel electrode was almost like any other. However, since the development of many new base-metal alloys, various types of electrode coverings, different welding processes and considerable increase in the severity of the service conditions, it has become extremely important in many service environments that the proper filler metal (electrode or welding rod) composition is used.

For example, this is very important where service temperatures above 800° F are involved. In most dissimilar-metal combinations, metallurgical changes take place across the dissimilar-metal bond† at temperatures above 800° F.

That these changes can be extremely critical is illustrated in Fig. 8 of a near failure by cracking in a repair weld. This repair weld was made in the shop on a carbon—½% molybdenum steel valve (0.16% C, 0.47% Mo) with a carbon-steel electrode prior to field welding with carbon-molybdenum steel electrodes into a 900° F, 900-psi main steam-piping system of a power station. Although the ½% molybdenum "dissimilarity" in composition might have been considered inconsequential, the elevated-temperature service caused carbon migration from the carbon-steel repair weld into the adjacent carbon—½% molybdenum steel with sufficient weakening in the affected carbon-steel repair weld to

† According to AMERICAN WELDING SOCIETY terminology, the *bond* is "the junction of the weld metal and the base metal."

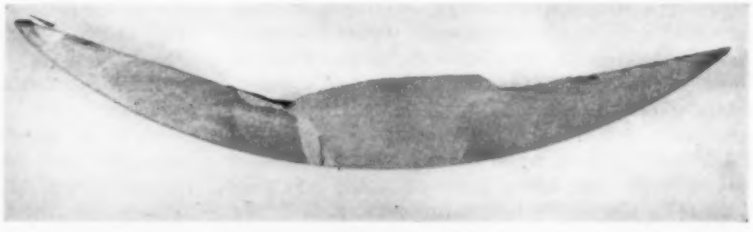
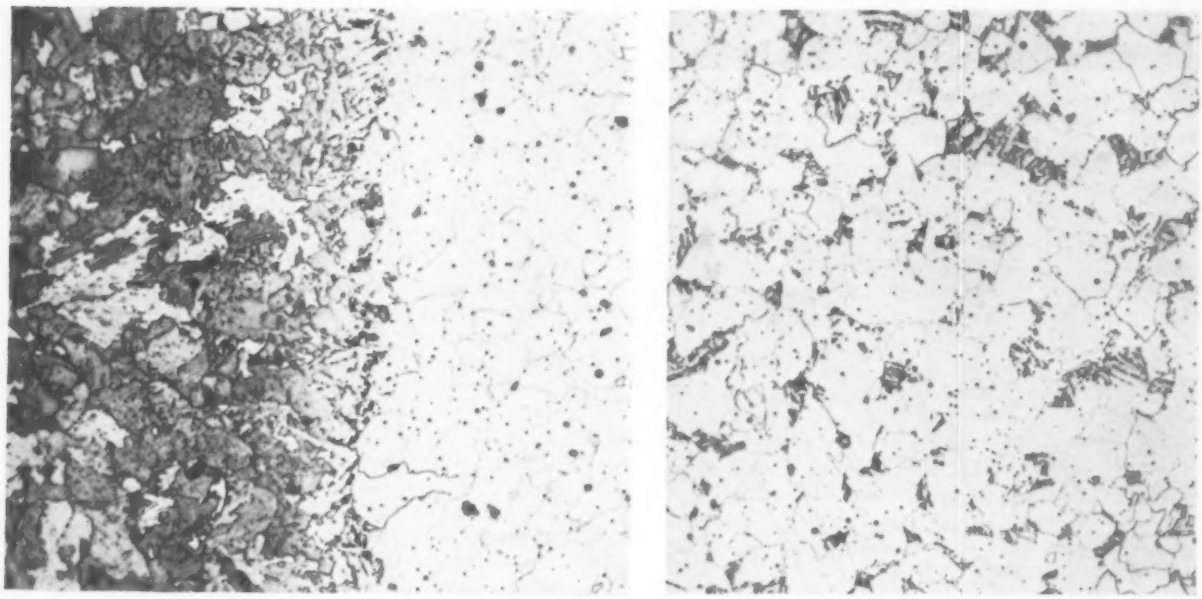


Fig. 8—Cracking in carbon-steel repair weld adjacent to carbon – ½% Mo steel field weld joining the carbon – ½% Mo steel valve to carbon – ½% Mo steel pipe. X 1

Fig. 9—Cracking in carbon-molybdenum steel weld deposit made in 1% Cr – ½% Mo base metal. X 1, left, and X 10, right



(A) (B)

Fig. 10—Photomicrographs of (A, left) "bond" zone between decarburized carbon – ½% Mo weld metal and 1% Cr – ½% Mo base metal and (B, right) structure of carbon – ½% Mo weld metal away from the decarburized zone. X 500

permit initiation and propagation of a crack.

The crack was not present in the original weld. Neither radiographic examination, which originally indicated a sound weld, nor any other established test would have revealed the existing metallurgical dissimilarity resulting in a potentially dangerous condition (sometimes also referred to as a "metallurgical notch").

Figure 9 illustrates a developing service failure in a joint in which 1% Cr – ½% Mo base metal has been welded with a carbon—½% molybdenum welding electrode after service for approximately 2 yrs at 1000° F. Here again, the carbon has migrated from the carbon—½% molybdenum weld deposit into the 1% Cr – ½% Mo base metal, leaving a decarburized zone in the weld deposit adjacent to the bond (see Fig. 10).

In the majority of cases observed in dissimilar-metal joints in several power-plant and refinery installations where failures have been developing gradually, cracking has started from the inside diameter. Detection, therefore, is extremely difficult, if not impossible, unless routine evaluations are made by specific methods.

Whereas bend tests are widely employed to evaluate the embrittlement in pipe joints as, for example, by graphitization, they are not conclusive in determining the "weakening" across a dissimilar-metal joint. Bend bars removed from the majority of dissimilar-metal pipe joints containing gradually propagating cracks near the root of the weld have nevertheless been bent satisfactorily to 180 deg. It is more apparent, therefore, that the carbon migration leaves the affected area extremely notch sensitive, though not affecting significantly the bend ductility.

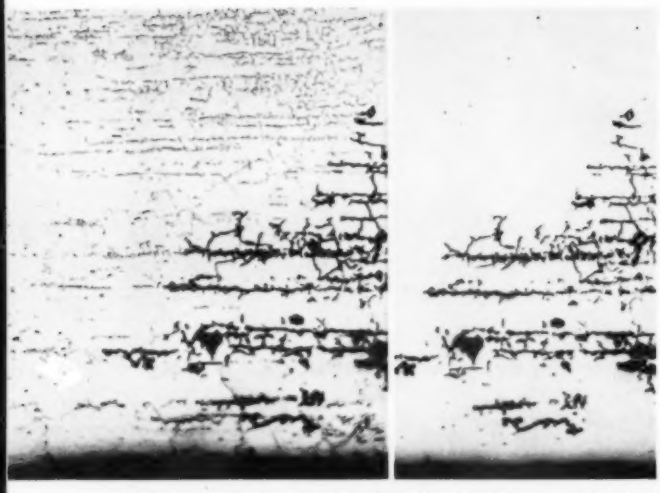


Fig. 11—Selective corrosion of ferrite phase in partially ferritic Type 308 stainless-steel weld deposit in hot-water pipe line containing residual chlorides. X 200. (Reduced by 50 % upon reproduction)

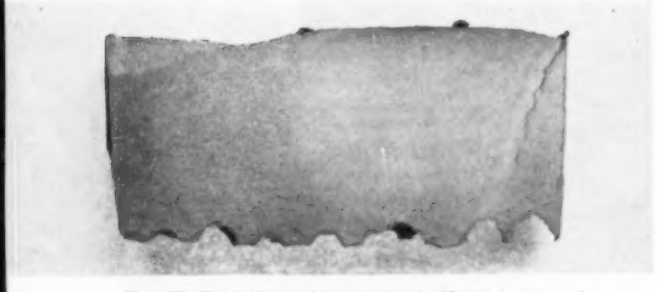


Fig. 12—Typical cracking in heat-affected zone of carbon – $^1/_2$% Mo base metal after service at temperatures over 850° F. X $^3/_4$

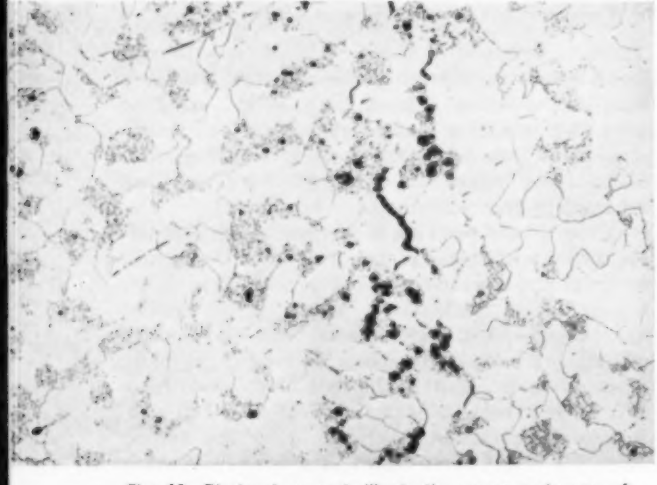


Fig. 13—Photomicrograph illustrating severe degree of graphitization in carbon – $^1/_2$% Mo base metal. X 100

Fig. 14—Cracking in bend-test specimens upon bending by 5 – 15 deg indicating severe embrittlement due to graphite formation in heat-affected zone of carbon – $^1/_2$% Mo base metal

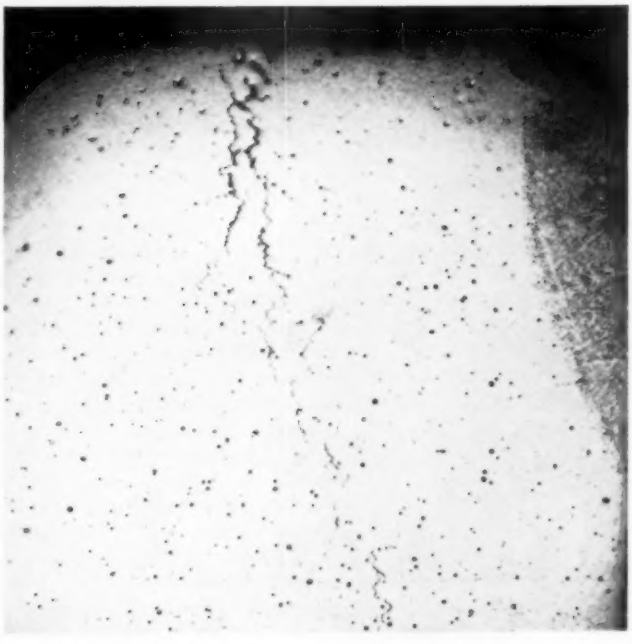


Fig. 15—Cracking in heat-affected zone of Type 347 stainless-steel pipe joint in service at temperatures above 1050° F. X 35

The dissimilarity is likely to be more critical between steels of different type compositions than between steels of the same type of composition but of different chemical analyses. For example, at temperatures exceeding 800° F the dissimilarity between a carbon steel and a carbon—$^1/_2$%molybdenum steel is more critical than the dissimilarity between a 1$^1/_4$% Cr – $^1/_2$% Mo and a 2$^1/_4$% Cr – 1% Mo alloy steel.

In general, weld deposits are more adversely affected by decarburization than wrought base metal.

The metallurgical structure in weld deposits may also require consideration in material selection. Figure 11 illustrates a corrosive failure in a Type 304 stainless-steel welded-pipe joint made with a Type

308 stainless-steel electrode. The corrosive solution attacked the ferrite phase in the Type 308 weld deposit. The composition of the Type 304 pipe base metal was higher than usual in nickel and lower in chromium contents, thus providing an essentially fully austenitic metallurgical structure. If the weld metal had been Type 310, which normally is austenitic, the type of corrosive attack shown in Fig. 11 would not have occurred. Selection of Type 310 base metal, of course, would also have been desirable.

Base-metal Composition

The selection of a base metal for service conditions somewhat more severe than environments on which previous experience is available, is frequently based upon the interpretation of the results obtained in accelerated mechanical or chemical laboratory tests.

Considerable effort is expended to simulate service conditions as closely as possible. Nevertheless, frequently the results of the "simulated" tests differ considerably from the subsequent service experience. One difficulty, of course, is that the specimens used in the simulated tests usually are of considerably simpler design, are far better machined to eliminate surface effects, and are much smaller than the fabricated assembly exposed subsequently to the critical service environment. Generally, the test is accelerated by increasing the temperature and/or test loads in order to reduce the period necessary to obtain results within several months or a few years; for example, in creep test, periods of 1000, 5000 and 10,000 hrs are normally employed. During subsequent service, however, failures may develop after service periods of 20,000 or 100,000 hrs.

One of the most widely known examples is the unexpected development of graphitization[6] in carbon-steel and carbon-molybdenum steel piping after service at temperatures of over 800° F. Figure 12 illustrates a crack in the heat-affected zone parallel to the weld of a carbon—$^1/_2$% molybdenum steel pipe which has started at the OD and has penetrated about $^2/_3$ of the wall thickness. That the graphitization which preceded the cracking (see Fig. 13) has severely reduced the ductility in the heat-affected zone is apparent from the bend specimens shown in Fig. 14.

Because of the propensity of certain types of carbon and carbon—$^1/_2$% molybdenum steels to lose ductility by graphite formation at temperatures exceeding approximately 800° F, carbon and carbon-molybdenum steels are no longer used in steam power-plant service at temperatures exceeding 750 and 800° F, respectively.

Although many laboratory studies have been conducted to evaluate the formation of graphite in carbon and carbon—$^1/_2$% molybdenum steels, these studies have not been able to reproduce the same critical type of graphite formation which is causing embrittlement and cracking in piping installations in high-temperature service.

In recent years, a number of steam power plants in the United States and in Germany have been constructed for steam temperatures at 1050, 1100° F and still higher temperatures. Extensive laboratory tests have indicated that the columbium stabilized 18% Cr – 8% Ni stainless-steel material (Type 347) should be satisfactory. However, after 6 to 18 months of service the 6 to 11-in. OD piping systems fabricated showed a significant tendency to cracking in the heat-affected zone, illustrated in Fig. 15.

In many service environments, the fabrication may be exposed to mechanical or thermal fatigue or shock. Many laboratory test programs have been, and are now being, conducted to evaluate the effects of mechanical and thermal cycling on engineering materials. Unfortunately, it is extremely difficult, if not impossible, to correlate laboratory test results with actual service conditions. Such correlations are difficult since, at elevated temperatures, gradual changes tend to occur in the metallurgical structure of the materials involved in the service applications which are not easily apparent from the similated laboratory studies usually conducted over relatively short periods of time.

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6. Thielsch, H., Phillips, E. M., and Jerome, Jr., E. R., "Consideration in the Evaluation of Graphitization in Piping Systems," THE WELDING JOURNAL, **34** (6), Research Suppl., 286-s to 294-s (1955).

Correction

"Electroslag Welding—a New Process for Heavy Fabrication"
by R. David Thomas, Jr.
The lead photograph in the February 1960 issue of WELDING JOURNAL, page 111, was incorrectly credited to Chantier Naval de l'Atlantique.
The correct name is Chantiers de l'Atlantique.

The Editors

Fig. 1—Artist's conception of launching of X-15 manned research vehicle

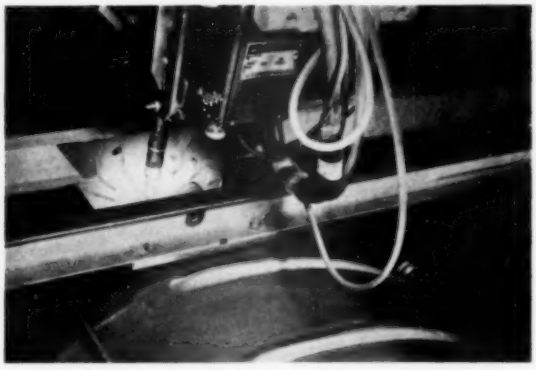


Fig. 4—In welding wing attachment fittings to X-15 lox-tank shell, inert-gas-shielded tungsten-arc head is mounted on a cam block to follow the oval shape of fittings

Gas Tungsten-Arc Welding Aids Construction of Manned Research Vehicle

BY W. L. ARTER

Representing more than two million man-hours of engineering effort, North American Aviation's rocket-propelled X-15 manned research vehicle has been designed to probe the fringes of space to bring closer to reality man's dream of flying to the stars (see Fig. 1).

Capable of attaining altitudes as high as 100 miles above the earth's surface and flying at speeds in excess of 3600 mph, the X-15 represents one of the most prodigious efforts to date to control manned flights beyond the limits of the earth's atmosphere. Built by the Los Angeles Division of North American the vehicle's first powered flight was completed successfully on September 17th when it was released from a B-52 bomber ten miles above the Mojave Desert in California.

Designed to carry a half ton of instrumentation and powered by a Reaction Motors engine producing as much power as a flight of four F-100 interceptors, the X-15 is believed by many to be the most significant flight vehicle ever built. It is the result of a combined national research effort conducted jointly by the Air Force, Navy and the National Aeronautics and Space Administration.

In fabricating the X-15, North American departed from traditional design and construction practice in several important instances. Most significant, perhaps, was in the extensive use of structural welding—about 65% of the space vehicle's airframe is of welded construction.

Fabricated with Inconel X skins fastened to Inconel X and A110-AT titanium ribs, stiffeners and frames, the X-15 fuselage was built in four major sections: forward fuselage, forward tank (lox), aft tank (ammonia) and aft fuselage. The forward fuselage structure consists of three major skin sections welded together with inert-gas-shielded tungsten-arc automatic heads to form one continuous shell-like surface extending from the attach point of the forward nose cone to the forward lox tank. In fabricating, the skinning was completed before the inner structure, reversing the normal manufacturing sequence.

To form each of the tank sections (forward and

W. L. ARTER, is Representative, Engineering Services, Air Reduction Pacific Co.

aft), four Inconel X skins were butt-welded using inert-gas-shielded tungsten-arc heads (see Fig. 2). Details such as stiffeners, installation brackets and torus bulkheads were spot and seam welded into position. The aft fuselage was made of both Inconel X and titanium construction. Frames were made from several titanium segments welded together, while gussets and angles were in turn welded to the frame.

All welding was normally accomplished on sections of the X-15 in an annealed condition. Titaniun welding was done in a plastic bag using argon supplied from a bulk station as a protective shield.

Industrial gases including oxygen, nitrogen, argon, helium, hydrogen and acetylene are used throughout the North American plant.

In all, North American has built three of the X-15 research vehicles. Their wide range of missions will include obtaining knowledge of actual flight conditions beyond the earth's atmosphere, aerodynamic heating and heat-transfer data, and the measurement of heat on structural components.

Every aspect of the X-15 flights will be tape-recorded by airborne recording instruments. Data obtained in this manner will also be supplemented by interrogation from ground telemetry stations along a 485-mile flyway which has been marked as the X-15 High Range.

Repairs in Modern Railroading... Throttle Costs, Highball Profits

BY C. R. STRUTZ AND E. D. UECKER

To the streamlined railroad industry, keeping one step ahead of the cost-profit squeeze means using every available cost-cutting technique. Electric welding processes have contributed much towards cutting railroad costs, especially in the equipment repair shops.

For example, a diesel locomotive crankshaft is a very expensive item, costing between $4500 and $6500, depending upon engine size. Due to normal bearing wear and occasional failures, a major southwestern railway company found they had enough worn crankshafts to warrant their own rebuilding program.

They started using manual covered-electrode welding, but found that the average cost for rebuilding one bearing was around $79. (There are 8 main and 6 crank bearings in a 12-cylinder crankshaft, and 10 main and 8 crank bearings in a 16-cylinder crankshaft.)

Then they switched to mechanized submerged-arc welding (see Fig. 1). Their production went up, and costs dropped to around $12 per bearing. On a 16-cylinder crankshaft, that's a saving of over $1200. (For the actual cost comparison, see Table 1.)

Crankshafts aren't the only diesel engine parts that wear out—pistons do, too. Alco Products, Inc., Auburn and Schenectady, N. Y. and St. Louis, Mo., have found that inert-gas metal-arc welding is ideal for rebuilding aluminum diesel locomotive pistons (see Figs. 2 to 4).

Both 9- and 12½-in. diam pistons are rebuilt.

Table 1—Crankshaft Rebuilding Cost Comparison

Covered-Electrode Welding	Cost
Manual rod consumption per average bearing service, 15 lb at $0.22/lb	$ 3.30
Average labor time per bearing, welder and helper combined, 16 hr at $4.71/hr	75.36
Total (per bearing)	78.66
Total for 16-cylinder crankshaft (18 bearings)	$1415.88
Automatic submerged-arc welding	
Submerged-arc welding wire consumption per bearing, 10 lb at $0.21/lb	$ 2.10
Flux composition required per bearing, 25 lb at $0.13/lb	3.25
Average labor time per bearing, welder and helper combined, 1½ hr at $4.71/hr	6.28
Total (per bearing)	11.63
Total for 16-cylinder crankshaft (18 bearings)	$ 209.34

C. R. STRUTZ is Eastern Zone Sales Manager, Oxweld Railroad Dept., Linde Co., New York, N. Y. and E. D. UECKER is a Welding Sales Engineer, Linde Co., Houston, Tex.

Fig. 1—Submerged-arc welding deposits uniform, hard-wearing surface to worn diesel locomotive crankshaft bearing, saving major U.S. railroad about $1200 per crankshaft

The 9-in. size is welded automatically (see Fig. 2) and the $12^1/_2$-in. size semiautomatically (see Fig. 3), due to valve pockets which interrupt the contour of the crown.

By removing the old worn ring carrier and gas metal-arc welding a new cast aluminum carrier in place, the piston is returned to service at about one-half the new-part cost. Pistons can be rebuilt as many as three times—a 300% increase in service life. In fact, reclamation has increased the life of some pistons by more than 2,000,000 miles.

Inert-gas-shielded arc welding is ideal for other applications, such as rebuilding worn brake-beam trunnions at New York Central System's Beech Grove Shops, near Indianapolis, Ind.

Brake beams are set up in a lathe with the torch mounted at one end. The torch has two indexed positions, for rebuilding $1^5/_8$- and $2^5/_8$-in. diam trunnions. Each coach brake beam has two of each size.

To rebuild a single brake beam (four trunnions) took 30 min with manual covered-electrode welding. With gas metal-arc welding, the same operation requires eight minutes (see Fig. 5).

This time saving cuts rebuilding costs by over $1.00 per beam. Since the Beech Grove shops rebuild about 5000 beams per year, this one application saves the New York Central between $5000 and $6000 each year.

Fig. 2—Automatic inert-gas metal-arc welding of worn 9-in. locomotive piston at Alco Products

Fig. 3—Manual inert-gas metal-arc welding on larger aluminum piston

Fig. 4—From left to right: worn piston; degreased and machined piston; reclaimed piston after welding; machined and polished piston ready for shipment

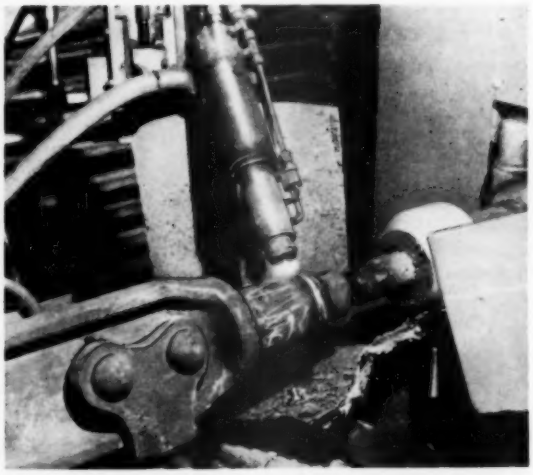
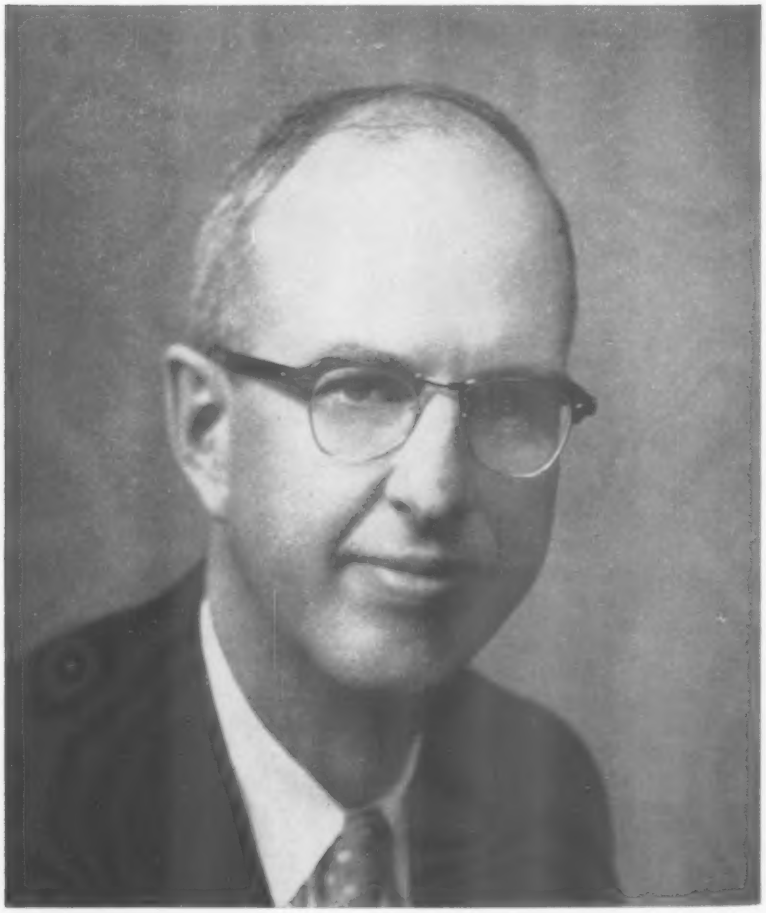


Fig. 5—Inert-gas metal-arc welding a worn brake-beam trunnion at a N.Y. Central repair shop

Society News

Thomas Elected American Welding Society President



R. David Thomas, Jr.

The newly elected officers of the AMERICAN WELDING SOCIETY for the 1960–61 fiscal year were introduced to the membership at the opening session of the 41st Annual Meeting and Welding Exposition in Los Angeles on April 25th.

R. D. Thomas, president of Arcos Corp., has been elected president of the SOCIETY succeeding Charles I. MacGuffie whose 1959–60 term expires on May 31, 1960. Mr. Thomas is currently completing his term as first vice president. He will assume his new duties together with the other officers-elect on June 1st when the new term officially begins.

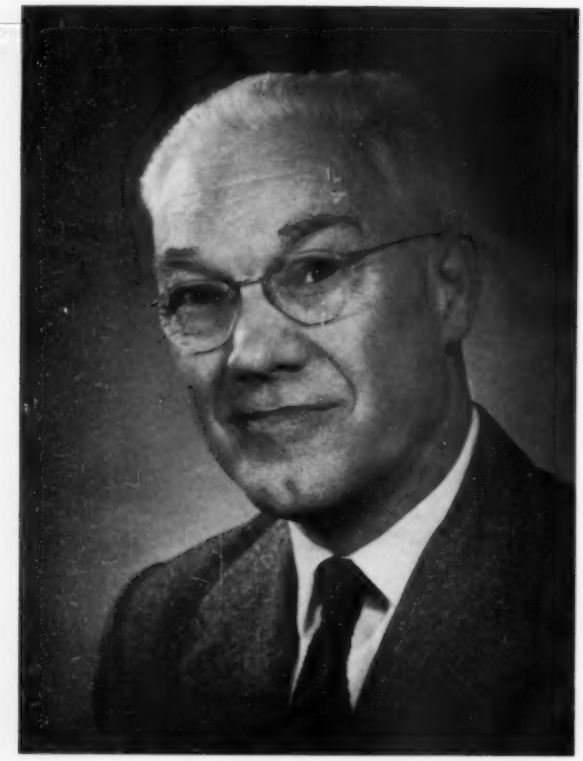
H. E. Rockefeller was appointed to the 3-year term (1960–63) as treasurer of the SOCIETY. Mr. Rockefeller is now completing a 3-year term of service at this formerly elective post.

This year, in accordance with the new By-laws, three vice presidents without seniority have been elected. They are:

John H. Blankenbuehler, design engineer, Hobart Brothers Co., Troy, Ohio.

A. F. Chouinard, director of research and development, National Cylinder Gas Division, Chemetron Corp., Chicago, Ill. Mr. Chouinard was re-elected to office.

Clarence E. Jackson, associate manager, Electric Welding Development, Linde Co., Newark, N. J.



John H. Blankenbuehler

A. F. Chouinard

Clarence E. Jackson

H. E. Rockefeller

The newly elected directors-at-large are: R. B. McCauley, chairman, Welding Engineering Dept., Ohio State University; John Mikulak, assistant to the vice president in charge of manufacturing, Worthington Corp., Harrison, N. J.; Ernest F. Nippes, professor of metallurgical engineering and director of welding research, Rensselaer Polytechnic Institute; Robert D. Stout, head of the dept. of Metallurgical Engineering, Lehigh University.

The district directors for the new term are: *New England* (District 1)—George W. Kirkley, consultant and welding engineer, Electric Boat Division, General Dynamics Corp., Groton, Conn.

Southeast (District 4)—James M. Shilstone, partner, Shilstone Testing Laboratory, Baton Rouge, La.

West Central (District 7)—Lester L. Baugh, welding process engineer, Allis-Chalmers Manufacturing Co., Springfield, Ohio.

Western (District 10)—David P. O'Connor, Power General Shops Foreman, Department of Water and Power, City of Los Angeles.

The National Nominating Committee will consist of C. I. MacGuffie, chairman, G. O. Hoglund, R. W. Clark, B. Gates and the eleven district representatives.

The new district representatives who will serve on the National Nominating Committee for the 1960–61 term are as follows:

Helmut Thielsch, Grinnell Corp., Providence, R. I. (No. 1); S. T. Walter, Air Reduction Sales Co., New York City (No. 2); D. H. St. Louis, A. H. St. Louis Co., Utica, N. Y. (No. 3); G. M. Slaughter, Oak Ridge National Laboratory, Oak Ridge, Tenn. (No. 4); E. T. Scott, Sr., Cleveland School of Welding, Cleveland, Ohio (No. 5); R. H. Hoefler, Kaighin & Hughes, Inc., Toledo, Ohio (No. 6); L. C. Monroe, publisher, *Welders' Digest*, La Porte, Ind. (No. 7); J. R. Warn, Havens Structural Steel Co., Kansas City, Mo. (No. 8); J. M. Barnes, Black, Sivalls and Bryson, Inc., Oklahoma City, Okla. (No. 9); F. R. Drahos, Byron Jackson Div., Borg-Warner Co., Los Angeles, Calif. (No. 10); Eric Kinnaird, Pacific Car and Foundry Co., Renton, Wash. (No. 11).

In addition to the newly elected candidates, the following national officers will continue in office:

Directors-at-large: A. A. Holzbaur, D. B. Howard, J. L. York, Jay Bland, F. G. Singleton, C. B. Smith, J. R. Stitt. Since Mr. Jackson has been elected a vice president, the unexpired portion of his term (1961) will become vacant.

District Directors: E. E. Goehringer (No. 2), J. W. Kehoe (No. 3), H. E. Schulz (No. 5), J. N. Alcock (No. 6), G. O. Bland (No. 8), C. L. Moss III (No. 9), C. B. Robinson (No. 11).

Past-President Directors: G. O. Hoglund, C. I. MacGuffie.

DIRECTORS-AT-LARGE

R. B. McCauley

John Mikulak

Ernest F. Nippes

R. D. Stout

DISTRICT DIRECTORS

G. W. Kirkley
District 1

J. M. Shilstone
District 4

L. L. Baugh
District 7

D. P. O'Connor
District 10

WILLIAM SPRARAGEN RETIRES AFTER 42 YEARS OF SERVICE TO WELDING

A Tribute...

...from The Editors

The WELDING JOURNAL has a special debt of gratitude to acknowledge on this occasion of the retirement of William Spraragen, for it was he who founded the present publication, 38 years ago, in 1922. Anyone who glances through the small pages of the very modest early issues cannot fail to be impressed by the responsible and dedicated point of view by which the founders so soon established a new technology and spread the sinews of AWS throughout our national economy. A leading force among these founders, Mr. Spraragen continued for 33 years to edit and manage the JOURNAL and, through its pages, to labor for the growth and strength of this SOCIETY. Notable in itself, this service, however, is only one aspect of the many-sided career of this tenaciously principled man who so carefully helped to lay strong foundations for the organization of the science of welding technology.

In retrospect, William Spraragen's career unfolds in a multiple growth of interests and responsibilities. He was born on May 20, 1895, in Warwick, N. Y.

Close-up of 1924 AWS Annual Fall Convention shows William Spraragen bottom row center

Graduating from Union College in 1916 with a B.E. degree, he started out as a test engineer at Acorn Insulated Wire Co. Following this, with a short term at Westinghouse Electric and Mfg. Co. in 1917, he next tried the teaching field as an instructor of electrical engineering (1917–18) at Oklahoma A&M College. In 1918, the war found him as a ballistics engineer with the War Department. In this period he started his official career in welding as assistant chairman and research assistant to the Welding Research Committee of the National Research Council and the Emergency Fleet Corp. At

At the Fifth Annual Dinner, 1926 . . . Mr. and Mrs. Spraragen face each other at center

the end of hostilities, in 1919, he returned to teaching as instructor in electrical engineering at the University of Washington at Seattle.

In 1920, he returned to organized welding, this time to stay. He was made secretary of the Division of Engineering of the National Research Council operating jointly with the American Bureau of Welding, the newly created research arm of AWS, and he continued in this post to 1935. From here on, his varied career branches out into a number of

concurrent responsibilities. In 1922, he founded the present WELDING JOURNAL and continued as editor and business manager through 1954.

In 1926, he added the duties of technical secretary of the AWS, a post he held until 1942. Along with these duties at AWS, in 1935 he was named executive secretary of the Welding Research Council of the Engineering Foundation; in 1945, he assumed his present position as director. Since 1948 he has been

At the IIW Assembly, Madrid, 1956 . . . Mr. Spraragen is flanked by Mrs. Spraragen and A. Amirikian

a member of the governing council of the International Institute of Welding, having served from 1954 to 1959 as secretary of the American branch of that group.

During all these years he found time, somehow, to write the *Handbook of Engineering Mathematics;* to compile and edit the first two editions of the WELDING HANDBOOK; to write, edit, coedit and coauthor books, sections of books and numerous articles on research practice, phases of welding and critical reviews of welding literature. He wrote the section on welding in the *Encyclopedia Britannica* and the *Mechanical Engineers' Handbook.* In addition to his literary efforts, Mr. Spraragen managed to serve as an engineering consultant to numerous industries through the Spraragen Engineering Corp.

The AMERICAN WELDING SOCIETY in 1940 conferred upon him the Samuel Wylie Miller Medal for outstanding service to welding and in 1955 made him an honorary member. He is a member of a number of engineering societies: AWS (Hon.); AIEE; ASME; SNAME; API; ASM; the Metals Science Club and the Engineers Club.

June 1950 . . . William Spraragen is caught at his desk in the JOURNAL office at headquarters

In 1926 he married Eunice Thone, his former secretary, whose patience and understanding helped carry him through the extraordinary schedule of work, self-imposed, which saw him laboring through many long hours. But the burden was on his shoulders all through those early pioneering years. With extremely small funds for assistance he relied heavily on one or two loyal aides whose services he has gratefully acknowledged.

Such a chronology does not in any way begin to describe William Spraragen, the man. Strong-willed and clear-thinking, he never swerved from one unselfish purpose: to promote with all his energy the sound growth of a body of knowledge for the benefit of mankind. There was never any question where private interest, even his own, conflicted with the greater purpose. Yet this fierce determination was tempered with a strong sense of humanity which found him by the side of all who needed help, including those who sincerely disagreed with him. Always prompt to acknowledge his own errors, he believed in honesty and sincerity. When questioned as to his surprising efficiency, he was fond of saying that it stemmed from inherent laziness—the principle of least work!

These are some of the qualities for which he is known. They have gained him the deep respect of all those who have come to know him. William Spraragen has raised a high ideal for those who would follow the trail he has blazed.

THE EDITORS

October 1955 . . . Mr. Spraragen happily accepts his Honorary Membership certificate from President Humberstone

. . . from The Council

Bill Spraragen probably wrote these words which form the opening paragraph of the By-laws of the Welding Research Council:

"The general purpose of the Welding Research Council shall be: (*a*) to organize and administer cooperative research projects in the welding field; (*b*) to stimulate, aid and guide welding research in the universities, endowed laboratories and commercial laboratories of the country; (*c*) to critically digest the world's welding literature and make the results as widely available as possible in readily usable form; (*d*) to publish and disseminate original welding research information."

What better can I say than that these purposes have been fulfilled to the utmost? He it is who has organized and administered, stimulated, aided and guided, critically digested, published and disseminated. In doing so he made the countless friends who now crowd around to shake his hand and wish him well.

Bill Spraragen need not worry about the future of the enterprises and publications he has nurtured through the years. He himself has brought them to adulthood and he can now watch with great pleasure as they continue to flourish and develop. His is an honorable retirement in the truest sense of achievement. We of the Council wish him the utmost happiness.

E. E. Michaels
CHAIRMAN, WRC

At the National Meeting, 1957 . . . Mr. and Mrs. Spraragen flank the late Miss M. M. Kelly, former AWS Secretary

. . . from The Society

During the past forty-two years, many individuals —prominent leaders in industry and commerce, educators, representatives of government agencies —have contributed to and profoundly influenced the steady growth, expanding prestige and significant accomplishments of the American Welding Society. The names of Founder and First President Comfort A. Adams and long-time Secretary Marguerite M. Kelly are intimately linked with the organization and development of the Society.

However, throughout the entire life of the Society, the record of William Spraragen is unique. An engineer, a scientist, a planner and promoter of research, associate and confidant of many of the world's greatest business executives and research directors, a man of limitless energy, keen perception, broad vision and firm convictions, he initiated, expanded and made possible the present success and great scope of AWS technical activities, the Welding Journal and the Welding Handbook. Part of his time for many years, and most of it for the past five years, has been devoted to the activities of the Welding Research Council and of the International Institute of Welding, demonstrating his unusual ability in raising funds, recruiting personnel and reporting results for important research projects.

Probably no one has contributed so much to the American Welding Society as has William Spraragen, through his wise counsel, his loyalty and devotion, his effective and generous contributions to the advancement of welding technology.

Fred L. Plummer
SECRETARY, AWS

KEEPING YOU POSTED

by Fred L. Plummer

● During the morning of February 23rd, Mr. J. F. Lincoln discussed with President-elect R. D. Thomas, Jr., Technical Secretary Fenton, Information Secretary Phillips, Journal Editor Rossi and your Secretary, possible actions which might increase general recognition of the reliability, economy and serviceability of welded fabrications, and the development of simpler, more general and less restrictive rules which can be used to insure the production of sound, low-cost weldments.

● During the afternoon, President MacGuffie, President-elect Thomas and your Secretary discussed problems relating to local and regional expositions; the preparation, printing and distributing of sponsored manuals, books and other publications; pension and other fringe benefits for staff members; the economic aspects of codes and specifications; formation of new and discharge of old committees (tasks completed); additional activities, staff members and projected budgets.

● The following day and again on March 3rd, Past-president J. H. Humberstone and your Secretary discussed plans for organizing a committee consisting of top industry executives who will help plan and sponsor the Annual Assembly of the International Institute of Welding which will be held in New York during April, 1961, in conjunction with the AWS Annual Meeting and Welding Exposition. Mr. Humberstone will serve as chairman of this important committee.

● As part of Welded Products Month activities, Past-president Humberstone will speak before the April 8th dinner meeting of the Detroit Section.

● On February 25th, President MacGuffie and your Secretary embarked on another of their ill-fated air trips, leaving New York on an early nonstop Electra flight to Atlanta with a continuing flight to Huntsville and its Redstone Arsenal. On-time arrival over Atlanta, unfortunately, coincided with the arrival of a cold front and low ceiling, circling for one and one-half hours, and finally flying on to Mobile. A new try which included a plane flight to Birmingham and a 100-mile drive in a rented car with President MacGuffie acting as pilot, was successful in bringing us to Huntsville at six-thirty and just in time to join Dan Daley, R. V. Hoppes, R. Conners, J. Melonas, W. McCampbell, J. K. Dawson and others of a group now organizing a new AWS Section. Following a social period and excellent dinner, your Secretary discussed AWS activities and President MacGuffie gave engineers from Redstone Arsenal and others a glimpse at the future of fusion welding.

● The following day, while President MacGuffie visited Redstone Arsenal, your Secretary returned to Washington for a conference with Rear Admiral E. H. Thiele and Lieutenant Commander J. D. Crowley of the U. S. Coast Guard. Admiral Thiele is Chief Engineer of the Coast Guard, Head of the Ship Structure Committee and Vice-chairman of the American Council of the International Institute of Welding.

● Other Washington activities on March 1st included conferences with E. H. Arnold and T. J. Wilson of our International Cooperation Administration, and attendance at the opening session of the President's Conference on Occupational Safety at which Vice-president Nixon and Secretary of Labor J. P. Mitchell were the principal speakers before an audience of perhaps 2000 persons gathered in Constitution Hall.

● Completing a full day, your Secretary was met at the Baltimore station and enjoyed dinner with A. C. Earlbeck, his son Tom and associates J. Jones and V. Marshall, all of Earlbeck Welding Supplies, Inc., guests Ed Farmer, Dick Clark and George Linnert. During the evening, Linnert presented the second in a series of six lecture-class periods to almost one hundred engineers and others representing major metal fabricators in the Baltimore area. Interest, as evidenced by the spirited discussion and suggestions stimulated by this talented engineer and scientist, was keen and continuous during the two and one-half hours devoted to

AWS DIRECTORS-AT-LARGE

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	A. E. Pearson	D. B. Howard	F. G. Singleton
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AWS PAST-PRESIDENT DIRECTORS

J. J. Chyle G. O. Hoglund C. P. Sander

the meeting. Following a review of the evening activities with sponsor Earlbeck and lecturer Linnert in one of Baltimore's newest and best restaurants, your Secretary retired to a roomette for an early morning ride back to the New York headquarters.

● Education Activities Chairman C. E. Jackson and Education Secretary A. L. Phillips proudly welcomed fifty "students" to the first five-day course of the AWS School of Welding Technology in New York's Commodore Hotel on March 7th. President MacGuffie, Vice-president Thomas, Treasurer Rockefeller and your Secretary joined Director Jackson at a special dinner to welcome representatives of industry attending this course devoted to gas-shielded arc welding and to pay tribute to Secretary Phillips and the fabricating company leaders who served as instructors.

● Meetings of the American Council of the International Institute of Welding, its Executive Committee and some of the fifteen commission groups were held in New York on March 8th. About fifty members of the Council met in the board room of the American Bureau of Shipping to designate delegates, experts and observers, and make plans for their participation in the IIW Annual Assembly to be held in Liege, Belgium, next June. It is expected that some forty representatives of the United States will attend this assembly.

● This same evening, following dinner at the Engineers Club as guests of Past-president Hoglund, your Office Assignment Committee, of which he is chairman, met in your Secretary's office to prepare recommendations covering the assignment of 1960–61 members of the Board of Directors to the Administrative, Districts, Publication and Promotion, and Technical Councils and to the Executive and Finance Committee. Those in attendance in addition to Chairman Hoglund and your Secretary were: C. I. MacGuffie, R. D. Thomas, Jr., J. J. Chyle and A. F. Chouinard.

● A special committee consisting of Exposition Chairman J. E. Norcross, Convention Chairman J. E. Dato, NWSA President A. C. Axtell, Director G. W. Kirkley and L. D. T. Berg met with your Secretary on March 14th to consider problems and develop recommended policies concerning the sponsoring of local or regional expositions by AWS sections.

● The following day, Past-president O. B. J. Fraser met with your Secretary and Frank J. Mooney to prepare data for another special committee of which he is chairman, with Treasurer H. E. Rockefeller, Past-president H. W. Pierce, President-elect R. D. Thomas, Jr. and W. Spraragen as members. This group will study pension-plan, vacation and holiday, insurance and other staff "fringe benefit" policies.

● That evening your Secretary attended a reception given by the American Concrete Institute as part of their annual meeting, greeting long-time friend and ACI President Phil M. Ferguson of Austin, Tex., Secretary-treasurer W. A. Maples, Mr. and Mrs. A. Amirikian, A. A. Bates and many other friends active in this institute.

● Other important contacts of this week included conferences by phone or in person with J. H. Humberstone, Society attorney Holloway, Richard Miller of U. S. Steel, C. E. Jackson, Fred Outcalt, Arthur Gatewood, Howard Cary, W. Spraragen, and on March 17th, one with Treasurer H. E. Rockefeller to review income and expense report prepared by Assistant Treasurer Frank Mooney covering operations for the first nine months of the current fiscal year which ends May 31st.

AWS School of Welding Technology

Five-day Course on Inert-gas and Co_2 Welding
(Duplicate of course given March 7–11, 1960)

Location: New York City

Date: May 23–27

Fee: $75.00

Who: The course is slanted to the needs of the engineer whose company uses welding as a fabrication tool.

Why: To give him a grasp of the fundamentals of a specialized group of processes and introduce him to applications, relative costs, and design considerations.

Enrollments are limited to fifty and lists will be closed immediately after fifty applications have been accepted. Plan to attend this course and take advantage of the latest and most authoritative information on gas-shielded welding processes. Send for prospectus and application form immediately, by addressing Arthur L. Phillips, Secretary, Information & Education, 33 W. 39th St., New York, N. Y.

NOW AVAILABLE

WELDING HANDBOOK SECTION III—Miscellaneous Metal Joining and Cutting Processes

In its pages is found the most accurate, up-to-date knowledge on welding, cutting and allied joining methods obtainable.

This Section contains chapters on: Forge Welding, Thermit Welding, Induction Welding, Surfacing, Metallizing, Brazing, Soldering, Welding of Plastics*, Adhesive Bonding of Metals*, Oxygen Cutting, and Auxiliary Oxygen Cutting Processes, Arc Cutting, Ultrasonic Welding*, Welding by Cold Workings*, Stud Welding.

Section III contains over 500 pages and 400 illustrations and tables. Copies may be obtained from the American Welding Society, 33 West 39th Street, New York 18, N. Y. List price $9.00 per copy.

*These subjects have never before been included in an AWS Welding Handbook.

● An uneventful airplane trip later that day brought your Secretary to Warren, Ohio, where he joined President C. I. MacGuffie who had spoken the previous night at a meeting of the AWS Nashville Section. A large group of members gathered at Victoria Restaurant in Youngstown for the social hour, dinner and meeting of the Mahoning Valley Section planned by Jack Huna and conducted by Chairman E. A. Craig with the assistance of officers R. Hoffman, J. Glass and R. H. Foxall. District Director J. W. Kehoe spoke briefly, your Secretary outlined Society organization and activities, and President C. I. MacGuffie presented "A Glimpse at the Future of Fusion Welding," as Director-at-large J. Deffenbaugh, Constitution and Bylaws chairman I. A. Oehler, Manufacturers' Committee Chairman Ted Long and several past chairmen of the section joined other members in this excellent meeting. Secretary-treasurer Foxall announced a $500 gift by the Taylor-Winfield Foundation to the United Engineering Center Building Fund bringing the total gifts for the Mahoning Valley Section well above their assigned goal.

● Before returning to New York the following evening, President MacGuffie and your Secretary visited: (1) the well-equipped shops of Warren's very large high school where vocational students in welding are given 1900 hours of instruction over a 2-yr period under the direction of Principal M. Mollenkopf, Instructors M. Bushwack, R. Haynes and their associates; (2) the large plant of Federal Machine and Welder Co. where E. A. Craig and R. H. Foxall explained the large, intricate, special purpose resistance welding machines and presses under construction, and Vice-president Ralph N. Lietzell and several of his associates were hosts at a very enjoyable luncheon; and (3) the equally interesting plant of Taylor-Winfield Corp. where President Long personally described the special automatic production line units which can transform a sheet of metal into a complete complex product by a series of successive operations. Staff associates Al Maternach, J. Huna and many others contributed to this exceptionally informative visit.

● Assistant Secretary Frank J. Mooney has been appointed Chairman of the New York Group of National Association of Exhibit Managers.

FRED L. PLUMMER

Welcome

• Sustaining Member

Effective Feb. 1, 1960

NIBCO Inc., Elkhart, Ind.

This company, formerly the Northern Indiana Brass Co., has recently introduced a line of seamless carbon steel welding fittings. Named "Husky," this line consists of 45- and 90-deg. elbows, straight and reducing tees, and concentric and eccentric reducers in 1-through 6-in. sizes, schedule 40. Material is A106 grade B and the Huskys meet ASTM Specification A234.

The largest manufacturer of copper tube fittings in the world, NIBCO also manufactures brass valves and fittings for the plumbing, heating and cooling industry.

Sustaining Member Representative—Lee Martin.

• Supporting Companies

Effective March 1, 1960

Avica Corp.
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Newport, R. I.

C-B Southern, Inc.
P O Box 19267
Houston 24, Tex.

H. E. Weise, Inc.
2155 Sorrel Ave.
Baton Rouge, La.

Lincoln Electric Co.
17124 Wyoming Ave.
Detroit, Mich.

National Welders Supply Co., Inc.
State and Gesco Sts.
Charlotte 8, N. C.

Shilstone Testing Laboratory
P O Box 123
Baton Rouge, La.

OVER THE TOP

Chairman Willis A. Duncklee presents check to Secretary Plummer bringing the Hartford Section to 118% of their $700 goal for the UEC building fund

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FOUNDED IN 1919 FOR ADVANCING THE SCIENCE AND THE ART OF WELDING

FRED L. PLUMMER
NATIONAL SECRETARY

PENNSYLVANIA
6-9220

May 1, 1960

AN INVITATION TO AUTHORS

— to participate in the American Welding Society's
42nd ANNUAL MEETING AND EXPOSITION
New York, N. Y., April 17–21, 1961.

Gentlemen:

The American Welding Society will hold its 42nd Annual Meeting and Exposition in New York, N.Y., on April 17–21, 1961.

Each year our Society offers opportunities to Authors for bringing their outstanding work, development and research to the attention of our Membership and the welding and metals industry, by having previously unpresented and unpublished papers presented at its national meetings.

The Society's Technical Papers Committee will be happy to receive your application for entry in the 42nd Annual Meeting activity. All applications, abstracts and manuscripts will be screened by the Committee, and Authors will be notified sometime in October 1960 regarding acceptance.

Each abstract should be sufficiently descriptive to give the Committee a clear idea of the content of the proposed paper. In any case, it must contain *not less than 500 - but preferably not more than 1000 - words.* Also, in order to place the Committee in the best possible position to evaluate these papers, it is suggested that each abstract be accompanied by a complete manuscript.

The Committee reserves the right to consider all applications on the basis of acceptance for placing on the 42nd Annual Meeting program, or consideration for placing on the 1961 National Fall Meeting program, the next national meeting of the Society. Papers may be considered for publication in the *Welding Journal* regardless of acceptance for presentation at either Meeting.

Papers dealing with latest developments in (1) design and fabrication of all types of weldments, including machinery, (2) welding of aircrafts and rockets, (3) fabrication and maintenance of equipment used for radioactive applications, (4) pressure vessels and storage tanks, (5) equipment and pipe lines used in petroleum industry, (6) structures, (7) automation as applied to welding processes, (8) resistance spot, seam and projection welding, (9) gas-shielded arc welding, (10) new processes, (11) welding of castings and composite structures, (12) welding of "new" alloys, (13) weldability of high-strength steels, (14) welding of aluminum, magnesium, zirconium, titanium, molybdenum and like metals, (15) brazing, (16) maintenance, (17) surfacing, (18) soft soldering, (19) adhesive bonding, (20) welding of plastics, and (21) practical applications or "how-to-do" topics are deemed to be of particular interest at the New York meeting. However, any papers dealing with the educational and informative categories of welding production, engineering, research and metallurgy, are welcomed as long as the subject falls within the field of our Society's activities.

Please fill out the Author's Application Form on reverse side of this letter, attach abstract thereto, and return to AWS. To assure consideration for the 42nd Annual Meeting program, your abstract must reach AWS not later than August 15, 1960.

Sincerely,

Fred L. Plummer

Fred L. Plummer
National Secretary

IMPORTANT: ABSTRACTS CONTAINING LESS THAN 500 WORDS AND THOSE POSTMARKED LATER THAN AUGUST 15, 1960 WILL NOT BE CONSIDERED.

AUTHOR'S APPLICATION FORM
FOR
AWS 42nd ANNUAL MEETING
APRIL 17-21, 1961

DEADLINE
AUGUST 15
1960

Complete in Full and Return to American Welding Society, Inc., 33 West 39th Street, New York 18, N. Y.

Date Mailed.....

Author's Name.....
Company or Organization.....
Title or Position.....
Mailing Address.....City.....State.....

If there are to be Joint Authorships, give name(s) of other author(s)
Name.....,
Address.....,
Name.....,
Address.....

PROPOSED TITLE (less than 10 words):.....

.....

SUBJECT CLASSIFICATION:

- Classify your paper by placing check mark in appropriate box:
  Industrial Application ☐ Engineering or Design Data ☐ Process Development ☐ Shop Practice ☐
  Original Research ☐ Education ☐ Other ☐ _____
  (state which)

ABSTRACT:

- Type, single spaced, an abstract of *not less than 500—but preferably not more than 1000—words* on separate sheet and attach to this form. Be sure to give sufficient information to enable Technical Papers Committee to obtain a clear idea of content of proposed paper.
- If complete manuscript is available, in addition to abstract, please attach copy hereto.
- Application Form and Abstract *must* reach AWS Headquarters not later than August 15, 1960, to assure consideration for 42nd Annual Meeting.

MANUSCRIPT DEADLINES:

- All manuscripts *must* be in the hands of the Technical Paper Committee not later than February 15, 1961. If received prior to December 15, 1960, every effort will be made to publish them in advance of meeting.
- It is expected that the Committee's selections will be announced sometime in October, 1960.
- If your paper is made a part of the program, which of the following manuscript deadlines will you be able to meet?
  December 15, 1960 ☐ January 15, 1961 ☐ February 15, 1961 ☐
- If manuscript is attached hereto, please check here ☐

PRESENTATION AND PUBLICATION OF PAPERS:

- Has material in this paper been previously presented in meeting or published?
  Yes ☐ No ☐ When?_____Where? _____
- Following presentation at the Society's 42nd Annual Meeting, would you accept invitation to present this paper before AWS Sections? Yes ☐ No ☐
- Papers accepted for presentation become the property of the Society, with original publication rights assigned to the *Welding Journal*.

RETURN TO AWS HEADQUARTERS. MUST BE RECEIVED **NOT LATER THAN AUGUST 15, 1960** TO ASSURE CONSIDERATION.
ABSTRACT MUST CONTAIN NOT LESS THAN 500 WORDS.

_____
Author's Signature

EDUCATIONAL ACTIVITIES

EAC to Repeat Course on Gas-shielded Arc-welding Processes

The AWS School of Welding Technology held its first course in March, in New York City. The subject was gas-shielded arc-welding processes. Within two weeks of the first announcement, the quota of fifty was reached and a waiting list was prepared for possible cancellations. When the course opened on March 7th, fifty people registered. There was still a waiting list of twenty, despite the fact that they had been told there was little likelihood of more than one or two people dropping out.

It became obvious, even before the first course had started, that a duplicate course would have to be held to accommodate the many additional people who wished to attend. This has now been scheduled and the duplicate course on gas-shielded arc-welding processes will be held in New York, May 23–27, 1960.

There were many lessons to be learned from the first course. Questionnaires completed by the students indicated their preferences. The majority of those attending preferred the basic approach given by the lecturers, rather than an advanced study into the more technical aspects of the process. They would prefer the course to be confined to the gas-shielded arc-welding processes, and time taken by other subjects could be used to expand the applications section of the course. Another suggestion made was to devote a morning or afternoon session to defects and their cure, trouble shooting, and problems and their solutions.

Changes considered an improvement will be incorporated into the next course.

A suggestion has been made that another duplicate course be held in California—preferably San Francisco—since many in the West Coast area would like to attend, but cannot travel as far as New York. If the demand is there, E. A. C. will certainly do its utmost to schedule a course in this area.

The gas-shielded arc-welding course was slanted to the needs of engineers who needed information on this subject, but who were not necessarily welding engineers. This was why the presentation was kept on a basic level. The attendees represented a good cross section of the engineering profession and included design, production and plant engineers, as well as draftsmen and management personnel.

The following syllabus was followed:

Monday: Clarence Jackson, Chairman of E. A. C. gave a short opening address of welcome.
Fundamentals of Welding. H. A. Sosnin, Welding Engineer, Nibco Inc.

Tuesday: Gas Tungsten-arc Welding and Cutting. James Cameron, Supervisor Welding Research, A. C. F. Industries; Edward Philipps, Head of Welding & Brazing Unit, Curtiss - Wright Corp.

Wednesday: Gas Metal-arc Welding. "CO_2 Welding." James Cameron, Supervisor, Welding Research, A. C. F. Industries; Carl Hellmer, Welding Engineer, General Electric Co.

Thursday: Jigs, Fixtures & Automation. John Mikulak, Asst. to Vice - president in charge of manufacturing, Worthington Corp.
Visit to New York Trade Schools to see, by means of closed circuit TV, the equipment previously discussed.

Friday: Inspection, Testing & Quality Control. Raymond C. Pearson, Welding Engineer, N. Y. Naval Shipyard.

A need for these specialized courses on welding exists. It is the intention of the Educational Committees of the AWS to provide the type of instruction and the number of courses required by the vast numbers of engineers who need further education on welding.

H. A. Sosnin explains fundamentals of welding with the aid of an oxyacetylene torch

Among the fifty attending the course were design, process, plant, production, development and maintenance engineers

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

AUTOMATIC WELDING

Robert Wilson, center, spoke on automatic welding at the March 8th meeting of Birmingham Section. Program Chairman W. W. McCain is at left and Section Chairman R. A. Davis is at right

SECTION MEETING CALENDAR

JUNE 3

SUSQUEHANNA VALLEY SECTION. Annual Dinner. 6:45 P.M. Foot Hills Manor, Shickshinny, Pa.

JUNE 4

ST. LOUIS Section. Annual Golf Tournament. Crystal Lake Country Club. Prizes, refreshments and games.

JUNE 11

CHICAGO Section. Annual Golf Outing.

JUNE 17

OLEAN-BRADFORD Section. Ladies' Night. Dinner Dance. The Castle, Olean, N. Y. Dinner 7:00 P.M. Election of officers. Dancing 9:00 P.M.—1:00 A.M.

JUNE 18

SAN FRANCISCO Section. Picnic Outing.

JUNE 21

DAYTON Section. Annual Picnic. Inland Activities Center.

Editor's Note: Notices for August 1960 meetings must reach JOURNAL office prior to May 20th, so that they may be published in the July Calendar. Give full information concerning time, place, topic and speaker for each meeting.

Alabama

AUTOMATIC WELDING

Birmingham—The March 8th meeting of the *Birmingham* Section was held at Salem's Restaurant Number Two. This was the regular monthly meeting, as well as the fourth session in the current lecture series sponsored by the Birmingham Section. The meeting was attended by a near-record crowd.

The following officers for the 1960-61 year were announced: *Chairman*, W. W. McCain; *Vice Chairman*, Enoch H. Carlson, Jr.; *Secretary-Treasurer*, K. V. Nickell; *Executive Committee*, R. A. Davis, Bruce M. Jones, Jr., T. C., Killingsworth, Sol P. Kimerling, D. W. Morgan and C. H. Faulkner, Jr.

The speaker for the evening was Robert A. Wilson, vice president and director, Application Engineering Department, the Lincoln Electric Co. Mr. Wilson gave a most interesting and informative talk on automatic welding.

FABRICATION OF ALUMINUM

Mobile—Robert A. Hay, welding engineer with the Engineering Services Department of Reynolds Metals Co., addressed the March meeting of the *Mobile* Section which was held at Korbet's Restaurant on March 17th. His topic "General Fabrication of Aluminum" was accompanied by projection slides. Of particular interest were the many varied and new uses of aluminum in the shipbuilding, heavy machinery and oil exploration industries.

Mr. Hay described the background of the principal aluminum welding processes and discussed the magnesium alloys used in ob-

HARD SURFACING IS TOPIC AT LOS ANGELES MEETING

Los Angeles Section Chairman Dick Hayes is shown introducing guest speakers at February 18th meeting. Vice-chairman John Wylie is at right

Principal speaker of evening was William L. Lutes. His talk dealt with the subject of hard surfacing

Past-president "Sandy" Sander, Chairman of Arrangements Committee for 41st Annual Meeting, outlines progress to date

taining higher strengths in the metal. Color slides demonstrated the uses of aluminum for concrete mixers, railroad hopper cars and gantry cranes.

California

HARD SURFACING

Los Angeles—The February 18th meeting of the *Los Angeles* Section, held at the Rodger Young Auditorium, featured William L. Lutes, manager, Hard Facing Division, the McKay Co., who presented "Facing Facts" to an audience of approximately 62 members and guests.

Mr. Lutes' subject was basic but complete enough to be helpful to many in clearing up some of the confusion and mystery surrounding hard surfacing. It briefly pointed out the work being done by various filler-metal committees in trying to bring more hard-surfacing knowledge to the users. The subject matter covered only that portion of the broad field dealing with electrodes, rods and automatic wires, reasons for surfacing, welding processes most commonly employed, factors affecting alloy selection and major alloys used for surfacing. Also the selection of the proper alloy for a number of common field applications was discussed. Mr. Lutes' past experience in this field made him exceptionally well versed in the subject matter.

Following Mr. Lutes' paper, a picture, in color, was presented on the story of stainless steel, through the courtesy of Republic Steel Corp.

HARD SURFACING

San Diego—The *San Diego* Section dinner meeting was held at the Midway Chuck Wagon on January 20th. Coffee speaker was Irving Krisman, a magician, who showed many interesting tricks and provided an enjoyable hour of fun.

Main speaker of the evening was E. Iverson, manager, Hard Surfacing Division, Alloy Rods Co., whose subject was "What Is Hard Surfacing and Why Is It Used?" Mr. Iverson's talk brought out many interesting points and was followed by a question-and-answer period.

Colorado

OXYGEN CUTTING

Denver—The *Colorado* Section held its meeting on March 8th at

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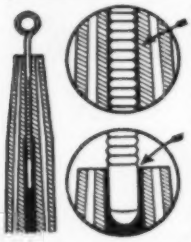

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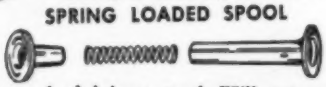

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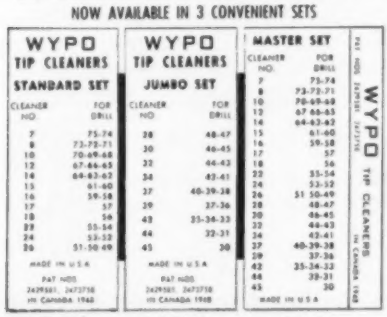

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Cavaleri's Restaurant in Denver. The group gathered at about 6:30 P.M. and, at 7:00 P.M., dinner was served. Coffee speaker for the evening was Scott J. Werner, special agent in charge of the Denver Office of the Federal Bureau of Investigation. His topic for the evening was the "Origin and Jurisdiction of the F.B.I."

H. Hooper, product sales manager of the Equipment Department of Air Reduction Sales Co., New York, was the main speaker for the evening. His topic was "Oxygen Cutting with Common Fuel Gases." Mr. Hooper discussed acetylene, natural gas and propane, what they are, how they burn and how to use each to the best advantage. His talk and the slides were very interesting.

Connecticut

COST REDUCTION

Glastonbury—The *Hartford* Section held its regular monthly meeting on February 16th at the Villa Maria Restaurant in Glastonbury.

E. L. Smith, manager, New York District, Lincoln Electric Co., presented an excellent talk on cost reduction in welding.

Florida

HIGH-STRENGTH STEELS

Miami—The *South Florida* Section met Wednesday, March 16th at the Miami Pioneer Club with 39 members and guests present.

Guest speaker for the evening was Dr. B. R. Queneau, assistant manager of metallurgy, Inspection and Research at the Tennessee Coal and Iron Division, U. S. Steel Corp., Fairfield, Ala. His lecture was on "Welding of High-strength Steels" and was accompanied by slides and the showing of a film, entitled "Welding Bridges."

Illinois

TUNGSTEN ARC

Kankakee—The *J. A. K.* Section held a very interesting meeting on March 10th at Mantoans Restaurant in Kankakee with a very fine speaker, Harold Davies of Airco, New York, who spoke on "Inert-Gas Welding." A brand new 16-mm film on inert-gas tungsten-arc welding was also shown. After the meeting, the attendance of

AT J.A.K. SECTION

Inert-gas welding was the subject discussed at the March 10th meeting of J. A. K. Section. Left to right are Chairman John Wolf, guest speaker Harold Davies, and Joe Sims

65 members and guests, went to the Kankakee Welding Co., where a live demonstration was put on. All had a chance to try their skill with the tungsten-arc torch.

Indiana

PLANT TOUR

Fort Wayne—The *Anthony Wayne* Section held its February meeting on Thursday, the 18th, starting with a dinner at 6:30 P.M. at Hall's East End Restaurant. This was followed by a brief talk by A. M. Stevenson, assistant plant engineer, International Harvester Co., Fort Wayne Works, preparing the Section for the various welding applications, and processes that would be seen later in the evening on a conducted plant tour of the Fort Wayne Works.

The plant tour which followed the dinner meeting proved to be very interesting, and practically all the phases of the production of heavy trucks was explained by trained personnel who served as guides.

CARBON DIOXIDE

Indianapolis—A dinner meeting of the *Indiana* Section was held in the Auditorium of the Indiana State Teachers Building on February 26th. Due to the snow only 31 members and guests attended.

J. A. Howery, Technical Service Department of National Cylinder Gas Co., was the speaker. His subject, illustrated by slides and a 16-mm film, was "Carbon-Dioxide Cored-Wire Welding Process." This included automatic and semi-automatic applications. His presentation was excellent and was followed by an interesting question-and-answer period.

RECTIFIER POWER SOURCES

South Bend—The *Michiana* Section was favored, on February 18th, with an excellent talk by G. K. Willecke, director of research, Miller Electric Mfg. Co., Appleton, Wis. His subject was "Rectifier Power Sources for Welding Applications." Dr. Willecke put special emphasis on the selenium rectifiers, although he also discussed motor-generators and mercury vapor, vacuum tube, copper oxide and silicon rectifiers. He pointed out applications for each type, then traced the history of welding power sources and discussed the elements and capacities of the selenium rectifiers.

He explained that the requirements of a welding power source are to supply current up to several-hundred amperes at voltages less than 100. It must be rugged to withstand the wide fluctuations in current requirements but, also, it must be simple to control, for the average operator won't bother with intricate settings. While the M-G sets satisfy these requirements, rectifiers can do so, too, with higher efficiencies and lower upkeep.

Dr. Willecke did not attempt to discuss the pros and cons of ac or dc, but based his talk on the premise that there was a need for d-c welding machines and then proceeded to show how the selenium rectifier would satisfy the requirements originally set up for a satisfactory welding power source. It was a most interesting and informative talk.

Richard K. Lee spoke on iron-powder low-hydrogen electrodes at the February 1st meeting of Wichita Section

These are some of the members and guests who were present to hear Mr. Lee's talk

Kansas

ELECTRODES

Wichita—On February 1st, the *Wichita* Section enjoyed a fine informative talk by Richard K. Lee of Alloy Rods Co., York, Pa., entitled "Iron-powder Low-hydrogen Electrodes." He outlined briefly the history and correct application of the iron-powder electrode. A lively question-and-answer period followed. An informal dinner at the Stockyards Hotel preceded the talk.

Maryland

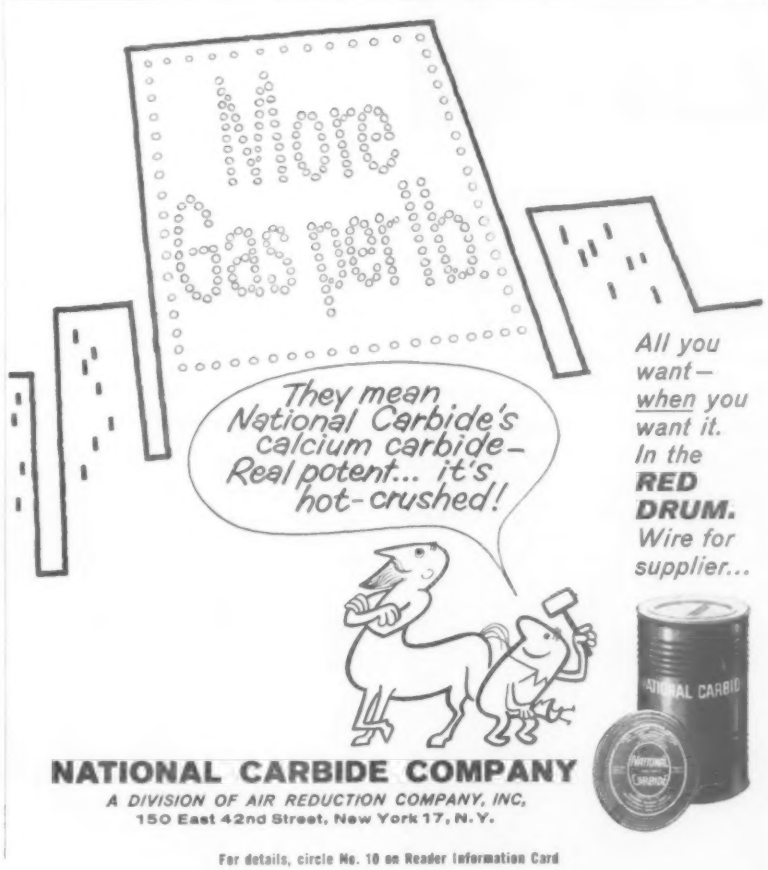
Baltimore—The regular monthly meeting of the *Maryland* Section was held on February 19th at the Engineers Club of Baltimore.

Al Kalpinski of the C. and P. Telephone Co. was the after-dinner speaker for the evening. He gave a most interesting talk, illustrated with slides and models, on the work the telephone company is doing on the switching system by means of "electronic computer" or "electronic brain."

The technical speaker was Julian S. Kobler, supervisory general engineer and head of Fabrication and Procedure Section, Naval Weapons Plant.

Mr. Kobler explained that successful fabricated structures can be economically built to quality levels required if there is close cooperation between the designer, metallurgist, welding engineer and the shops involved.

He emphasized the importance of choosing the proper materials for the fabrication and service requirements. Also, he explained that one should determine the welding process, weld filler metal and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DETROIT SPEAKER

Progress in the development of covered electrodes was outlined by Harry F. Reid, Jr. at March 11th meeting of Detroit Section

AT TECHNICAL MEETING

The March 17th special technical meeting of the Detroit Section was featured by a talk by Lyle Perry on the application and use of copper alloys in resistance-welding field

procedure to obtain the strength, soundness and quality of weld required, design the proper weld joints and following the weld sequence closely during the entire fabrication. In addition, he explained when and how to determine which type of nondestructive testing equipment one should use for maintaining a proper level of quality.

Michigan

COVERED ELECTRODES

Detroit—The regular monthly meeting of the *Detroit* Section was held on March 11th at the Engineering Society of Detroit. The Section's arc-welding group, and a good number of those whose interest embraces all aspects of welding, were treated to a well-organized and presented history of the development of covered electrodes, with a few significant thoughts for the future added thereto. Harry F. Reid, Jr., manager, Technical Service Division, the McKay Co., spoke before a good turnout of members and guests, most of whom had gathered earlier for dinner at nearby Carsons Restaurant. Mr. Reid traced the development and slow acceptance of the iron-powder covering in Europe, and the problems encountered, especially with control of ductility. He compared the manual electrodes developed since World War II and then went on to discuss current trends in the welding of stainless steel and hard surfacing. The future, he said, holds great promise for extension of semiautomatic welding with wire electrodes of tubular section, with alloying elements located in the center.

RESISTANCE WELDING

Detroit—A special technical meeting of the *Detroit* Section was held on March 17th at the Engineering Society of Detroit. The excellent color film prepared by the RWMA to show typical resistance welding methods and the machinery involved in each proved a good starting point for a discussion of "Application and Use of Copper Alloys in Resistance Welding Field" by Lyle Perry of the Tuffaloy Division of the Air Reduction Sales Co.

The usual enthusiastic group that has attended these special technical meetings found the presentation much to its liking and the discussion afterward continued for over a half hour. Mr. Perry discussed Class 1, 2, 3 and 4 alloys, and the materials to which they were best applied. Tip shapes and tapers were extensively discussed, together with renewable tips and adapters. The proposed renumbering system for tapers, using the Jarno system, was explained.

TOPIC IS CO_2 WELDING

Shown at the recent tour of the American Hoist and Derrick Co. plant in St. Paul, are, left to right: Sid Palmer, Dave Harris and Larry Erkenbrack. This meeting was sponsored jointly by the local Sections of AWS and AFS

COVERS QUALITY IN WELDED NUCLEAR EQUIPMENT

Quality in welded nuclear equipment was covered at length by E. C. Miller at February 11th meeting of St. Louis Section

Pictured above are some of the many members and guests who were present to hear Mr. Miller's talk

Minnesota

PLANT TOUR

St. Paul—The *Northwest* Section held its annual joint meeting with the American Foundry Society on February 8th.

Some 350 members and guests toured the American Hoist and Derrick Co. main plant in St. Paul. Live demonstrations on all phases of production were shown. Larry Erkenbrack, welding engineer for American Hoist, did an excellent job of showing the weldment section using the submerged-arc and carbon-dioxide processes.

New Jersey

ELECTROSLAG WELDING

Newark—Walter H. Wooding of Arcos Corp., Philadelphia, Pa., presented a description of the electroslag welding process at the *New Jersey* Section's monthly meeting on February 16th at the Essex House in Newark.

The speaker described the process and outlined its history, then showed how this method of welding can be applied to heavy-section vertical weldments. Mr. Wooding indicated that for welding heavy plates, electroslag welding offers certain economies over submerged-arc welding in that the welding process is continuous and is capable of depositing substantial quantities of weld metal per hour, as well as being more conserving on filler material for heavy welds than other processes. Various applications and types of welds possible with this process were illustrated, and the talk was concluded with a color movie showing a vertical butt weld being made in heavy plate with the electroslag process.

L. I. SPEAKER

G. R. Archer spoke on resistance-welding controls at March 10 meeting of L. I. Section.

SPEAKS ON ELECTRODES

Al Zeuthen, Socony Mobil, explains new developments in mild-steel electrodes to the New York Section. Tom Murray, technical secretary, sits nearby.

New York

WELDING CONTROLS

Bellmore—How to apply automatic resistance-welding controls to airspace vehicle construction was the subject of a talk given by G. R. Archer of the Budd Co., Philadelphia, Pa., at the March 10th meeting of the *Long Island* Section held at the Sunrise Village in Bellmore.

In principle, Mr. Archer stated, the control uses a feed-back voltage from the electrodes to the system which compensates weld current as necessary to assure consistency. Such variations as line voltage, surface cleanliness, electrode-diameter change, pressure variations, etc., influence welding voltage which, on being fed back to the control system, trigger the necessary compensation for consistent quality. The system presently is limited to single-phase equipment and has application on steel only.

This advance in quality assurance of resistance welding promoted lively discussion, following an excellent presentation by the speaker.

ELECTRODES

New York—On Tuesday, March 8th, the *New York* Section heard Albert W. Zeuthen speak on "New Developments in Mild-steel Electrodes." Mr. Zeuthen is welding engineer in the New York office of the Socony Mobil Oil Co. He is well known to most of the New York members as a result of his past years of activity as a member of the

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SYRACUSE SECTION FULFILLS UEC PLEDGE

At the February 10th meeting of the Syracuse Section, District No. 3 Director Joe W. Kehoe was presented with a check covering the group pledge to the United Engineering Center fund. Left to right, above, are Membership Committee Chairman Harry Miller, Mr. Kehoe, Section Chairman Frank R. Fudesco and Section Treasurer Hugo Klix

Executive Committee of this section.

Mr. Zeuthen graphically showed the differences between various classes of mild-steel electrodes now on the market to be considered by the engineer and operator in selecting the proper electrode for the job. He described (1) the composition of the various coverings used and the reasons for each; (2) the strength and ductility of deposits made with each type; (3) the specifications for each type; (4) the relative deposition rates; (5) the comparative cost of each and (6) their performance characteristics.

Iron-powder electrodes, said the speaker, are the latest and most dramatic improvement that has been made in mild-steel electrodes since the introduction of the low-hydrogen electrode. Mr. Zeuthen carefully explained the applications for iron-powder electrodes and their advantages over the other types. These higher-deposition rate electrodes are now available in the complete range of electrode types and classifications including low-hydrogen types. It was emphasized that care must be taken to preserve the low-hydrogen qualities of electrodes by storing them away from dampness and highly humid areas.

In summary, Mr. Zeuthen said that iron-powder electrodes are cheaper to use in the long run due to their high deposition rate. In addition they can produce consistently good properties equivalent or better than standard electrodes. These electrodes, therefore, are finding extensive use in the petroleum business and all other types of mild-steel fabrication.

As a sidelight Mr. Zeuthen cited the application of tubular welding wire with flux inside it for hard surfacing applications in a refinery.

Mr. Zeuthen's talk evoked a number of very pertinent questions which indicated that the talk was of interest to the welder, as well as the welding engineer.

QUESTIONS AND ANSWERS

Buffalo—One of the heaviest snowstorms of the season upset the program for the February 25th meeting of the *Niagara Frontier* Section. A record 65 dinner reservations attested to the interest in the scheduled talk by George W. Kirkley on "Welding on the Atomic Submarine Triton." The storm, however, grounded his plane 150 miles away. Chairman John Kaluzny had to improvise a program for the 45 members who had come to the Cypress despite 10 in. of snow. After a good dinner, he organized a question-and-answer program and an enjoyable and instructive session followed.

RESISTANCE WELDING

Olean—The speaker at the March 15th dinner meeting of the *Olean-Bradford* Section was James W. Mitchell of the Ford Motor Co. Mr. Mitchell spoke on the subject "Resistance Welding in Automotive Fabrication."

This talk on resistance welding was aided by the use of slides. These slides showed some of the many machines and operations that resistance welding performs in a complexed automated assembly line. The speaker stressed the importance of trouble-free equipment, standardization of tooling, proper maintenance, cleanliness, inspection as well as coordinated production scheduling for maximum production of assembled components. Also, he emphasized the continuing upgrading of present methods; for example, manual spotwelding to semiautomatic, and semiautomatic to full automatic.

Ohio

ELECTRON-BEAM WELDING

Cleveland—Members of the *Cleveland* Section were hosts to local research and design engineers interested in the operation and application of the new "electron-beam" welding process. The meeting and dinner were held at the Cleveland Engineering and Scientific Center on March 9th.

During the business portion of the meeting, the 1960 educational program was outlined and discussed by Stephen A. Butler, educational

ELECTRON-BEAM WELDING IS TOPIC OF TALK

R. Pagenkopf, William Farrell, H. Frericks and T. L. Dempsey review Mr. Farrell's discussion of electron-beam welding, which was presented at the March 9th meeting of Cleveland Section

committee chairman. This year, the program involved touring three industrial plants and one testing laboratory located in the Greater Cleveland area. It was pointed out that the program would be concluded on Wednesday, May 4th, at a dinner meeting in the Cleveland Engineering and Scientific Center. Technical material at the final meeting covered a "Bird's Eye View of Something New."

Guest speaker for the technical session was William J. Farrell, chief application engineer for Sciaky Brothers, Inc. He explained the principles of "Electron-beam Welding." What it is, how it works, and how it is used. The subject was chosen because it represents a very new process which holds promise of solving many difficult welding problems in the field of nonferrous metals.

WELDING SEMINARS

Six evening sessions devoted to different types of automatic welding comprised the 1960 educational lecture series sponsored by the *Dayton* Section of AWS. The series, held on successive Wednesday evenings starting March 23rd, was as follows:
Submerged Arc Welding—W. F. Hoffman, Jr., Linde Co.; Inert-gas-shielded Arc Welding—R. W. Tuthill, Air Reduction Sales Co.; Tubular-electrode Arc Welding—R. K. Wilson, Lincoln Electric Co.; CO_2-shielded Arc Welding—J. Headaphol, Hobart Brothers Co.; Tooling for Automatic Welding—L. Farnsworth, Automatic Machines and Equipment Co.; and Power Sources for Automatic Welding—G. Williams, Hobart Brothers Co.

TALKS ON SEMICONDUCTORS

The functions of semiconductors were treated at length by John J. Frye at the March 8th meeting of Dayton Section

SEMICONDUCTORS

Dayton—The *Dayton* Section met for a fried-chicken dinner and a technical meeting at Kuntz's Cafe on March 8th. A very interesting color film by the U. S. Steel Corp., entitled "The Mackirac Bridge Diary" followed the dinner.

John J. Frye of the Western Electric Co. presented a very enlightening talk on the functions of semiconductors and graphically depicted the formation and functions of the electrons in the semiconductors. In the question-and-answer period which followed the presentation, Mr. Frye explained the methods by which crystals are grown, purified and cut for manufacturing processes.

INERT-GAS WELDING

Youngstown—An amazing total of 46 members and guests braved a 4-in. snowfall and slippery roads to attend the February 18th meeting of the *Mahoning Valley* Section held at the Victoria Restaurant.

This gratifying turnout was treated to an excellent coffee-hour film on the highlights of the last twenty-five years of world events plus an excellent technical session.

The guest speaker was Tom McElrath, Laboratory Division Head, Linde Co., Newark, N. J. His talk on "Developments of Tungsten-arc and Consumable-electrode Inert-gas Welding" was one of the finest technical sessions this Section has had in the last few years.

The initial part of Mr. McElrath's discussion involved the development of the pilot-arc principle which provides a reliable starting of the arc. This facet of inert-gas tungsten-arc welding was thoroughly described including slides showing the cup design and the electrical connections used including an auxiliary power supply for starting. A 10-min. film was then shown on this process.

The second part of Mr. McElrath's interesting presentation covered the inert-gas metal-arc process for light-gage welding. This process is a combination of a new type power supply, gas mixture and torch equipment using 0.030-in. diam wire. The electrode in this method of welding is shorted to the material which then necks down and eventually forms the arc required for welding. This feature reduces arc blow to a minimum because of the shorter arc used. It also has an advantage of a smaller heat input and therefore reduces distortion as compared to other processes.

The power supply used for this type of welding controls the surge response for the welding current by using a variable-slope control. The gas mixture is a combination of argon and carbon-dioxide mixtures, with 75% argon and 25% carbon dioxide. A curved torch is used for the welding. A film was shown on this process which used a high-speed camera showing the actual on and off periods of the arc and also the difference using the argon-carbon dioxide mixture as compared with carbon dioxide only.

Several slides were then shown on the applications of the short arc principle including welding of window frames, automobile heaters, nose cones, boiler coils, fins on a fan blower housing and also pipe welding.

A lengthy question-and-answer

DISCUSSES INERT-GAS WELDING

The latest developments in inert-gas welding were covered by Tom McElrath at the February 18th meeting of Mahoning Valley Section. Left to right, are: R. H. Foxall, Section Chairman E. A. Craig, Mr. McElrath and M. Bushwack

TOLEDO SPEAKER

Selection of the best arc-welding methods for stainless and low-alloy steels was explained by Hallock C. Campbell at January 19th meeting of Toledo Section

period followed this talk.

ALLOY STEELS

Toledo—The *Toledo* Section had a very fine meeting on January 19th at the Toledo Yacht Club. Forty-six members and guests enjoyed a delicious dinner with 59 members and guests at the meeting.

Hallock C. Campbell, director of research at Arcos Corp., Philadelphia, gave an excellent talk on the "Selection of the Best Arc-welding Method for Stainless and Low-alloy Steels."

Dr. Campbell's talk covered the various methods and processes of welding stainless steel, and the economies and factors governing the cheapest method. He also had slides illustrating various jobs of stainless-steel welding.

Pennsylvania

WELDED DESIGN

Allentown—A joint meeting of the *Lehigh Valley* Section and the American Society of Civil Engineers was held on March 7th at Walp's Restaurant in Allentown. Carl L. Kreidler, chief engineer at Lehigh Structural Steel Co., Allentown, described how welding is coming into its own in steel construction.

Mr. Kreidler compared welded connections with the traditional riveted connections, saying that, although the unit price of welded designs is usually higher, the total cost to the contractor may be lower because it is possible to reduce the amount of steel required by from 4 to 33%.

•

A successful "Welding Metallurgy and Engineering" lecture series sponsored by the Lehigh Valley Section has just been concluded. The series consisted of 15 weekly sessions and was held at the Bethlehem High School in connection with their adult evening program.

The class of thirty was conducted by M. F. Couch, Bethlehem Steel Co., and Albert Bavaria, Lincoln Electric Co. The need and enthusiasm for such a program was very evident and it is hoped an advanced and more comprehensive program of this type can be offered next year.

WELDED SUBMARINES

Philadelphia—George W. Kirkley of the Electric Boat Division, General Dynamics Corp., and Director of AWS Diwtrict No. 1, presented a very interesting discussion at the February 15th meeting of the *Philadelphia* Section.

His subject, was the welding of the world's largest undersea craft, the Atomic submarine, *Triton*. Problems encountered in the construction, technical approaches and methods of control were discussed.

Interesting to welders is the fact that some 400,000 lb of filler metal were used in the construction of the *Triton*, her hull being 100% welded. This submarine is about 40% longer than those used in World War II, can cruise submerged for more than two months and can refuel at sea.

Mr. Kirkley showed some very interesting slides of subassemblies, weld sequence and some testing practices, using ultrasonic, zyglo, die-penetrant and X-ray testing.

Approximately 100 members and guests attended the meeting including some 15 from the New York Shipbuilding of Camden, N. J.

HARD SURFACING

Pittsburgh—A meeting of the *Pittsburgh* Section was held on Wednesday, March 16th, at the Mellon Institute with an attendance of 66. Prior to the meeting, 52 members met at dinner in the Hunt Room of the Hotel Webster Hall. The speaker for the evening was Howard S. Avery, research metallurgist, American Brake Shoe Co., Mahwah, N. J. His subject was "Hard Surfacing to Minimize Industrial Wear." It was well presented and received.

The presentation covered the savings in material costs by the use of hard surfacing, as well as the protection of parts subject to severe wear. Discussion also covered the special tests necessary for impact; gouging abrasion, grinding abrasion, erosion, galling, oxidation, corrosion and hot wear. Welding techniques and the use of arc and gas welds, with the resultant advantages and disadvantages, were thoroughly discussed.

ELECTRON-BEAM WELDING

York—On Tuesday, February 16th, the monthly meeting of the *York-Central Pensylvania* Section was held at the Viking Club in York. A total of 27 attended the dinner session and a total of 35 the technical session which followed.

The speaker of the evening was David L. Kelker, welding engineer, Special Products Department, Air Reduction Sales Co., Union, N. J. The subject was the "Electron-beam Welding Process." This process is used for the welding of rare metals such as zirconium, hafnium, ti-

AT MEETING OF PHILADELPHIA SECTION

Caught "watching the birdie" at the February 15th meeting of Philadelphia Section are: W. Shire, R. Moyer, O. Brown, H. Carr, A. Bruck, E. Siegman and J. Minister

NO. 5 OF A SERIES

"How to Design Welded Aluminum Structures"

Alcoa Verifies More Liberal Strengths in Design of Welded Aluminum Beams

Mr. Harry N. Hill, *Engineering Design Division Chief, Alcoa Research Laboratories, Aluminum Company of America, reports findings presented at the 1959 annual meeting of the American Society of Civil Engineers.*

The useful strength of a metal beam is seldom determined by reference to its tensile strength. Rather, a beam's load-carrying capacity is judged by its resistance to permanent deformation. Yield strength, therefore, is the common basis for beam design.

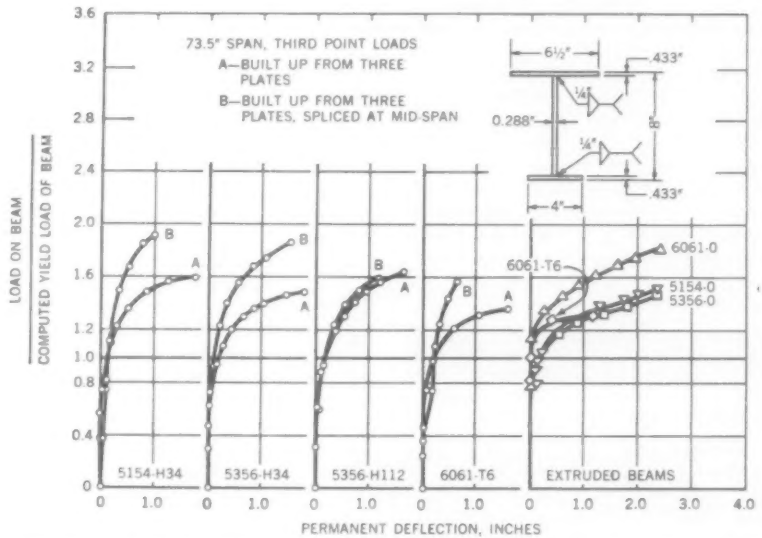
Yield strength values for welded aluminum alloy beams can be computed by applying the concepts of "reduced-strength zone" and "10-in. gage length yield strength" which were discussed in the first two articles of this series. The same procedure outlined in our third article for tension members can be utilized.

Total flange area for this computation is considered as the flange itself, plus one-third the adjacent web area between the flange and the neutral axis. Yield load of the beam is that which will produce a maximum bending stress equal to the yield strength of the tension or compression flange.

The validity of this design technique is demonstrated in the chart at right. Test pieces of aluminum alloy plates were welded to form an I cross section as indicated in the sketch. Both cold-worked and heat-treated alloys are included. "B" specimens were cut at mid-span and butt welded.

Permanent deflection at mid-span was measured with increasing loads. To compare actual yielding with calculated behavior, the applied loads are expressed as a ratio of the computed yield load.

Our tests indicate a high reliability of the computed yield load concept. Note that no significant permanent deflection occurred until the ratio of applied load to computed yield load reached 1.0.



COMPUTED AND ACTUAL YIELDING OF WELDED ALUMINUM ALLOY BEAMS

Further verification of this design rule was gained in tests of extruded beams with the same section as the welded beams. At the extreme right of the chart are similar plots for these beams. Yield loads were computed from tensile yield strengths. Note the similarity in yielding behavior between the welded and extruded beams.

Strength of long slender beams is sometimes limited by sidewise bending and twisting. Here the compression flange buckles much the same as a column. Such failure can be computed by the designer with the "equivalent slenderness ratio" method described in the *Alcoa Structural Handbook*. This technique relates the beam strength directly to design curves for columns. The column curves for welded aluminum alloy beams are constructed as discussed in article No. 4 of this series.

Previous articles in this series have featured reduced-strength zone, 10-in. gage length yield strength, strength of welded members in tension, strength of welded members in compression. Subsequent articles will deal with fillet welds and additional design data.

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SPEAKS ON TOOLING FOR PRECISION WELDING

A. W. Anderson spoke on tooling for precision welding at the March 8th meeting of North Texas Section. Left to right, are L. Hudson, Mr. Anderson, D. Hoban and Chairman F. Nordquist

These are some of the members and guests who were on hand to hear Mr. Anderson discuss the close tolerances currently being attained in welding various items ranging from coffee makers to missile cases

tanium and molybdenum under high-vacuum welding conditions and in thicknesses up to $^1/_4$ in. The process is now accepted industrially and welding equipment is available as a standard item. Fillet and butt welds can be made and filler metals used. The bulk of work now done is in thicknesses of 0.001 to 0.005 in.

Rhode Island

DISTORTION

Providence—The *Providence* Section held its monthly dinner meeting at Johnson's Hummocks on Wednesday, February 17th.

The Section was privileged by having John Mikulak, assistant to vice president of manufacturing, Worthington Corp., give a talk entitled, "Control of Distortion in Weldments."

Mr. Mikulak accompanied his talk with a series of slides that showed practical application and theory on how to control distortion in weldments.

Texas

PRECISION WELDING

Dallas—The *North Texas* Section met on Tuesday, March 8th, at the Western Hills Inn. A. W. Anderson, service engineer, Linde Co., was guest speaker for the evening.

Mr. Anderson's subject was "Tooling for Precision Welding." Illustrating his talk with slides, he discussed the close tolerances currently being obtained in welding various items ranging from coffee makers to missile cases. In most of the applications, no post-welding operations are required. Forty-seven members and guests enjoyed Mr. Anderson's presentation.

STEEL FORGINGS

San Antonio—A film entitled "Steel Forgings" secured from the Cameron Iron Works of Houston, was the highlight of the program for the March 7 dinner meeting of the *San Antonio* Section held at Capt. Jim's Cafe. It was a very interesting film showing the forging of stainless steel and valve assemblies.

An attendance promotion program was initiated at this meeting. Each member of the Section has been assigned a number; and at each monthly meeting a drawing will be held. If present and a member in good standing, the lucky number will be presented with a $5.00 award. Officers of the Section are ineligible, but at such time when their number is drawn, the $5.00 will be donated to the Section's Engineering Building Fund.

Utah

RECENT MEETINGS

Salt Lake City—A tour through the Utah Power and Light Gadsby Plant was made on January 14th by 50 members of the *Salt Lake City* Section. A need was felt to know what and how to go about getting adequate power for welding, etc. Questions were answered by personnel of the Utah Power and Light Co.

The February meeting was held on the 18th at the Panarama Inn. Robert A. Hay of Reynolds Aluminum gave a very good talk on "Aluminum and Its Future in Industry."

BRAZING AND SOLDERING ARE DISCUSSED

These are some of the members and guests present at the dinner preceding the February 19th meeting of the Fox Valley Section. Left to right, are: Second Vice-chairman G. H. Jacklin, Guest Speaker G. L. Hill, Secretary Bob Hart, Chairman Max Kern; Ken Loos, Past-chairman John Weigand, J. R. Dwyer, S. Manowske, Treasurer T. Krizenesky, J. P. Meer, J. Shackleton, E. Brehmer and A. Nelson. Mr. Hill spoke on low-temperature brazing and soldering of dissimilar and hard-to-join metals

PROGRAM DEALS WITH EDUCATION AND ENGINEERING

"Education and Engineering" was the title of the program at the February 18th meeting of Madison Section. Among the participants were, left to right, Prof. Washa, Prof. Harker, Prof. K. Wendt, Mark Vart, Prof. Braton, Prof. F. Schwehr, Prof. Lenz, Prof. Peterson and Prof. Ragatz

Wisconsin

BRAZING AND SOLDERING

Appleton—Over 100 were present at the February 19th meeting of the *Fox Valley* Section held at Miller Electric Manufacturing Co.'s Plant No. 2 where the firm maintains a school room and demonstration facilities.

The dinner which preceded the regular meeting was also well attended.

Gordon L. Hill, assistant manager, Aladdin Rod & Flux Mfg. Co., Grand Rapids, Mich., was the guest speaker. His talk covered the very broad field of low-temperature brazing and soldering of dissimilar, hard-to-join metals such as aluminum die castings, white metal, etc. He also conducted a live demonstration that held the interest of the group for over two hours—permitting anyone to do the actual brazing and soldering. This was the most interesting meeting, judging by attendance and interest, that this Section has had in a long time.

EDUCATION AND ENGINEERING

Madison—On Thursday evening, February 18th, the *Madison* Section tried something new and it proved to be a tremendous success. The program was called "Education and Engineering." This was student night. All fathers were urged to bring with them their sons or their neighbor's sons to learn what this popular term "Engineering" really means. Ninety-six members and their friends gathered at the Cuba Club in Madison at 6:30 P.M., where a delicious stuffed pork-chop banquet was served, hot and right on schedule. The program consisted of a panel made up of the chairman of each of the six engineering departments and moderated by Prof. Kurt Wendt, Dean of the College of Engineering at the University of Wisconsin. The panel members were Prof. Harker, chairman Mechanical Engineering; Prof. Ragatz, chairman Chemical Engineering; Prof. Peterson, chairman Electrical Engineering; Prof. Rosenthal, chairman Mining and Metallurgy Engineering; Prof. Washa, chairman of Mechanics Engineering and Prof. Lenz, chairman Civil Engineering. Each chairman described the work of his department and, together, they answered the many questions that arose from the floor. The program was reluctantly brought to a close by Fred Schwehr, after a 90-min inspiring and informative evening. This meeting was held in conjunction with the Madison Section of ASTE.

CUTTING AND GOUGING

Beloit—The *Madison* Section met at the Steak House in Beloit on March 17th. St. Patrick was honored by serving a corned beef and cabbage banquet.

The speaker, Jerry McEvilly of Arcair Co., presented a most interesting and informative talk. His address on the "Cutting and Gouging of Metal" was supported by slides. Sixty-three members and guests battled the icy roads to attend the meeting.

It was announced at this meeting that the Beloit Iron Works had demonstrated their faith in the Society by doubling their membership. The Madison section is proud of its membership progress this year. They started on June 1st with a membership of 76 and, as of March 17th, it was ninety-eight—an increase of 23%.

ACRO WELDER MFG. CO.
MILWAUKEE
WELDING ENGINEERS
MACHINERY BUILDERS
ESTABLISHED 1936

ACRO® general purpose spot-projection-butt-seam resistance welding machines.

ACRO-ARC® special purpose production welding machinery employing automatic arc welding processes.

ACROMATIC® special purpose production welding machinery employing resistance welding processes.

ACRO-MAGNETIC® magnetic force spot, projection, and percussion welding machines.

For details, circle No. 13 on Reader Information Card

Revolutionary General

has unique high peak power which resistance welding

A new type of control ignitron with coaxial design, the GL-7670, has been developed by General Electric to control high-current, short-duration power pulses utilized by a new "pulse-power" resistance welding method.

In the new General Electric ignitron, current passes down the inside of the tube from anode to cathode, then back up the wall of the tube to a *coaxial* cathode terminal at the top. This coaxial flow of current provides a magnetic *shield* to prevent the damaging arc deflection which such high peak currents could cause in standard ignitrons.

Available for immediate delivery, the new GL-7670 may be used to advantage in a number of other high peak current applications—such as capacitor discharge circuits. The new tube meets standard size "B" welder ratings, and has the same basic dimensions as the standard "B" welder ignitron. Full information from offices listed at right.

For details, circle No. 14 on Reader Information Card

Electric Control Ignitron coaxial design. Handles is vital to radically new method.

GL-7670
Coaxial Ignitron

FEATURES

1. Cathode connection at top
2. Compact dimensions
3. Easy to mount
4. Stainless steel jacket
5. Provision for temperature control

Progress Is Our Most Important Product

GENERAL ELECTRIC

9545-8481-29

Phone your nearest General Electric Power Tube Dept. office for samples and application assistance.

Schenectady, N. Y.
FRanklin 4-2211

Chicago, Illinois
SPring 7-1600

Clifton, New Jersey
GRegory 3-6387

Dayton, Ohio
BAldwin 3-7151

Los Angeles, Calif.
BRadshaw 2-8566

Newtonville, Mass.
WOodward 9-9422

Washington, D. C.
EXecutive 3-3600

For details, circle No. 14 on Reader Information Card

New Members

EFFECTIVE MARCH 1, 1960

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	201
Members	6,357
Associate Members	5,805
Students	249
Honorary Members	9
Life Members	15
Total	12,636

ALBUQUERQUE

Dawson, Robert K. (D)

BATON ROUGE

Chancey, H. C. (B)
Grey, R. L. (B)
Miller, M. E. (B)
Pecue, W. W. (B)
Smith, H. L. (B)
Watson, H. M. (B)

BIRMINGHAM

McElroy, Don (C)
Stephens, D. C. (B)

BOSTON

Austin, Theodore B. (C)
D'Aprile, Daniel P. (B)
Lusardi, A. G. (C)
MacLean, William F., Jr. (B)
Rolston, Paul W. (B)

BRIDGEPORT

Standt, Fred G. (C)

CANADA

Aves, Wm. W. (B)
Benner, Wesley W. (B)
Kular, T. S. (C)
McDonald, Charles A. (B)
Wheeler, N. L. (B)

CAROLINA

Smith, William E. (B)

CHICAGO

Gubbins, Vinton B. (C)
Johnson, K. F. (A)
Purcell, W. (C)
Roper, Robert J., Jr. (C)
Stracy, H. C. (C)

CINCINNATI

Schneider, August (C)

CLEVELAND

Brigance, Roy K. (C)
Brumbaugh, Bill (C)
Daykin, Edward (B)
Dullea, Robert A. (C)
Jochum, Michael J. (C)
Rettger, Edward G. (C)

COLORADO

McPherson, Byron (B)

COLUMBUS

Gwin, Wade (C)
Hamilton, William A. (D)
Hutt, Bruce L. (C)
Landig, Fred R. (C)
Oros, Alvin K. (D)

DETROIT

Block, Alan J. (B)
Goodrich, Jack (D)
Hirzel, Robert C. (C)
Kling, Richard J. (C)
Lyon, Lawrence A. (B)
McGuire, John L. (B)
Ott, Harold J. (B)
Paldan, Thomas (C)
Peterson, J. David (D)
Rosenberger, Maximilian (B)
Smith, Louis J. J. (C)

EASTERN ILLINOIS

Nelson, Axel Edward (B)
Seeds, Glenn (C)
Sirratt, Sherman R. (B)
Tibbs, Bill G. (B)

FOX VALLEY

Bogie, Robert J. (C)
Brehmer, Ernest (B)
Kaezor, Chester A. (C)
Meer, John P. (B)
Skjoldager, Jack D. (C)

HARTFORD

Keeley, John B. (C)

HOLSTON VALLEY

Bernard, George W. (B)

HOUSTON

Griffith, Dean O. (B)
Jackson, Harry L. (B)
Lanry, Elge A. (C)
Schoppe, Conrad J. (B)
Sullivan, Myrl F. (B)
Timmons, J. W. (C)
Yelinek, E. J. (B)

INDIANA

Carrier, John W. (C)

IOWA

Eastwood, Francis E. (C)

J.A.K.

Alexander, Charles F., Jr. (C)
Clesson, Robert D. (D)
Dawdy, Ward R. (B)
Togliatti, Anton D. (C)

KANSAS CITY

Scholler, Michael P. (C)

LONG BEACH

Reese, Leolf M. (B)

LONG ISLAND

Miller, Donald P. (C)

LOS ANGELES

Haight, Kenneth L. (B)
Harvey, W. M. (B)
Hendersen, Harold Charles (D)
Lee, Donovan H. (C)
Lynch, Robert (D)
Reff, Thomas G. (C)
Russell, Byron Lawrence (C)

MADISON

Witte, Robert F. (C)

MARYLAND

Bruce, Lee (B)
Sanders, Bernard W. (C)

MILWAUKEE

Ballard, Harry D. (B)
Schwamb, John H. (C)

NASHVILLE

Oakley, Bill T. (B)

NEBRASKA

Pedersen, Dan (C)

NEW JERSEY

Fox, James A. (B)
Loveland, Dudley E. (B)
Van Rohr, Herbert H. (C)

NEW YORK

Harley, Ernest (C)
Howard, Charles E. (C)
Jamul, Herbert (B)
Owens, Andrew (B)
Taylor, William D. (C)
Thomas, Ralph A. (C)

NIAGARA FRONTIER

Castle, Joseph (B)
Jackson, Samuel L. (C)

NORTH TEXAS

Ekholm, James P. (C)

NORTHEAST TENNESSEE

Duncan, Roy H. (B)
Gilliland, Ralph G. (C)

NORTHERN NEW YORK

Kelleman, Richard W. (C)

NORTHWEST

Herring, Denver L. (B)

NORTHWESTERN PA.

Black, George A. (B)
Pisarchick, Edward (B)

PEORIA

Abrams, Leon T. (B)
Baurer, Arthur E. (C)
Bostic, Riggs, Jr. (C)
Hamlin, Leroy Elmer (C)
Harwick, Merle D. (B)
Ripper, V. W. (B)
Smith, Herschel (B)

PHILADELPHIA

Birmingham, Raymond R. (D)
Bowers, Charles E., Sr. (C)
Brown, Samuel J. (B)
Fote, Samuel A. (B)
Frank, Paul D. (B)
Gallimore, John J. C. (C)
Hagan, Richard H. (D)
June, Carl R. (A)
Martin, John V. (D)
Orr, Willard J. (B)
Rhodes, Elmer E. (B)

PITTSBURGH

Artman, Richard E. (C)
Barkhurst, S. A. (C)
Bennear, Harry W. (C)
Otterman, Glenn E., Sr. (B)
Perrotta, Joseph W. (C)
Westlake, Perry R. (C)

PORTLAND

Brown, George O. (D)
Carlson, John A. (B)
Furrow, William H. (D)
McLain, James V. (D)
Moore, Cecil C. (D)

PROVIDENCE

Bagdagarian, Bagdasar (C)
Ekstrom, Robert (C)
Gill, George E. (B)
Hunter, Michael (B)
O'Toole, William (B)
Spear, Donald H. (B)
Taylor, William (C)
Turner, Herschel (B)

PUGET SOUND

Cearley, Ted E. (C)
Downey, James C. (B)
Prebula, John D. (D)

RICHMOND

Edwards, D. Therman (B)
Fitzgerald, J. P. (B)
Michie, J. Tevis (B)
Muscente, M. D. (B)
Rucker, Robert S. (C)

ROCHESTER

Fannon, James L. (C)
Kiehle, William D. (B)
Raut, Harold D. (B)

SAGINAW VALLEY

Carolan, Keith M. (C)

Whitten, James E. (C)
Owens, Donald B. (C)

ST. LOUIS

Buhr, Kenneth J. (B)
Carnall, John T. (C)
Cochran, John H. (C)
Guinther, Harold E. (C)
Kraus, Thayne L. (C)
Mason, Bill (C)
Von Till, Louis (C)

SAN ANTONIO

Holcomb, Preston T. (C)

SAN DIEGO

Zachavich, Edward (C)

SAN FRANCISCO

Greco, Vincent R. (B)
Kelley, James F. (B)
Lust, Victor (C)
Rogers, Robert G. (C)
Rowton, Lawrence R. (C)

SANGAMON VALLEY

Bartels, Robert E. (C)
Frankie, Edward K. (B)
Williams, Charles J. (B)

STARK CENTRAL

Christensen, Magnus (A)

SUSQUEHANNA VALLEY

Hartman, C. Wilbur (B)

SYRACUSE

Lombardi, Jack P. (B)
Morehouse, W. Stanley (C)
Shortt, LeRoy F. (B)

TOLEDO

Brazeau, Jack A. (B)
Mantel, Dale, Jr. (C)

TRI-CITIES

Mann, O. Clark (B)

WASHINGTON D. C.

Robinson, John W., Jr. (B)

WESTERN MICH.

Peabody, Darl H. (B)

YORK CENTRAL PA.

Mummert, H. L. (B)

MEMBERS NOT IN SECTIONS

De Sancy, Alain (C)
Edstrom, Goran (B)
De Carvalho, Fernando A. (B)
Garnham, Carlos Wiegand (B)
Guest, Arthur L. (C)
Henning, A. H. (B)

Members Reclassified During March 1960

ATLANTA

Thomas, John P. (C to B)

BOSTON

Atlas, Elliott J. (C to B)

CAROLINA

McGee, Thomas G. (C to B)
Scruby, George (C to B)

CINCINNATI

Levinstein, Moses A. (C to B)

MADISON

Knowles, Lawrence E. (C to B)

NEW YORK

Franklin, Bernard R. (C to B)

PHILADELPHIA

Hillman, Donald B. (C to B)

SUSQUEHANNA VALLEY

Adams, Gary (C to B)

TULSA

Augustine, Emil (C to B)

Authors . . .

please note!

All authors interested in presenting papers at the AWS 42nd Annual Meeting to be held in New York City on April 17–21, 1961 are advised of a change in preliminary arrangements.

The usual forms, "An Invitation to Authors" and "Author's Application Form," are printed as a detachable insert on pages 509 and 510 of this issue of the Welding Journal instead of being sent through the mails.

COLMONOY MODEL D

SPRAYWELDER

The Latest Refinement in Hard-Surfacing Equipment

Cut hard surfacing application costs and material waste with the fast-working, efficient Model D Spraywelder. It sprays over 12 pounds per hour, is up to 95% efficient. Constant development produced this new model, again proving the Spraywelder to be the one best tool of its kind. It's lighter and simpler to work than ever before, and has a large 15-lb. capacity hopper with a powder level indicator.

The Colmonoy Spraywelder produces smooth overlays of Colmonoy alloys that are fused to the base metal to form solid, welded wear resistant overlays that are easily finished, and wear up to forty times longer than hardened steel.

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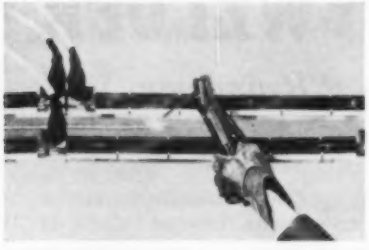
For details, circle No. 15 on Reader Information Card

NEWS of the industry

Nottingham Demonstrates Power Distribution Systems

An exhibition was held by J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y., in the South American suite at the New York Coliseum on March 1–3, 1960.

The economics and the mechanical details of several different types of portable distribution systems for electric power were the main features of the show. The systems included portable power distributions for welding, for strip-heater welding preheat, for general lighting, ventilation and power requirements, and for heavy-duty and explosion-proof circuits.



Introduced at the show was the company's new line of "building-block" electrical strip heaters for preheat while welding. The equipment is designed for quick plug-in installation. Power is distributed through a breaker panel with overload protection, serving several distribution blocks. Each block has output receptacles for "spider" leads and each "spider" can serve 3 strip heaters.

Other features of the show included the multiarc welding system which consists of a single, large transformer-rectifier power source, a series of resistor banks on the secondary side of the power source and the welding cables taken off the resistors. A 1500-amp power source of this type is considered capable of supplying constant potential power to about 30 welders. This is based on a short-time overload tolerance of the power source and a consideration of the statistically averaged duty cycle of the ordinary welding sequence. On this basis, the single source can replace about 30 motor-generator sets at a considerable saving in cost. Savings are also realized through lower operating costs, lower maintenance cost and ease in handling.

J. B. Nottingham is also a distributor of electrode holders and the Camlok line of connectors, receptacles and plugs.

Air Reduction Posts Record Sales

Sales of Air Reduction Co. Inc., for 1959, established a new record of $200,603,636, it was announced recently by John A. Hill, president. This is an increase of 14.4% over 1958 sales of $175,307,384.

Net income in 1959 was $14,850,600, an increase of 11.2% over 1958 net income of $13,349,885. Earnings for the year 1959 were $3.81, as compared with 1958 earnings of $3.47.

In the fourth quarter of 1959, sales were $49,550,743 and net income was $3,405,898. In 1958, fourth quarter sales were $46,536,009 and net income was $3,593,814. Earnings in the fourth quarter of 1959 were $.87, as compared with fourth quarter 1958 earnings of $.93.

1960 I.A.A. Convention

The International Acetylene Association will hold its national convention at the St. Francis Hotel, San Francisco, Calif., on Monday and Tuesday May 9–10, 1960.

Three technical sessions will feature the event followed by the annual business meeting and a banquet to be held in the Grand Ballroom of the hotel during which will take place the presentation of the Morehead Medal.

Monday morning will be given over to registration, a meeting of the Oxy-Acetylene Committee, a motion picture, the President's Reception, and luncheon, during which members will be addressed by featured speakers. On Monday afternoon, the first technical session will cover several important aspects of the topic "Cryogenics." The two topics for the technical sessions for Tuesday morning and afternoon will be "Safety and Safe Practices" and "Acetylene for Chemicals," respectively. Following the presentation of papers, the Annual Business Meeting will be held at 4:00 P.M. A reception will take place at 6:30 P.M. and the Morehead Medal Dinner is scheduled for 7:30 P.M.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1960 National Fall Meeting. September 26–29. Penn Sheraton Hotel, Pittsburgh, Pa.

1961 Annual Meeting & Exposition: April 17–21. Hotel Commodore, New York, N. Y.

NWSA

May 5–7, 1960. 16th Annual National Convention. Palmer House, Chicago, Ill.

IAA

May 9–10, 1960. Annual Convention. San Francisco, Calif.

ASM

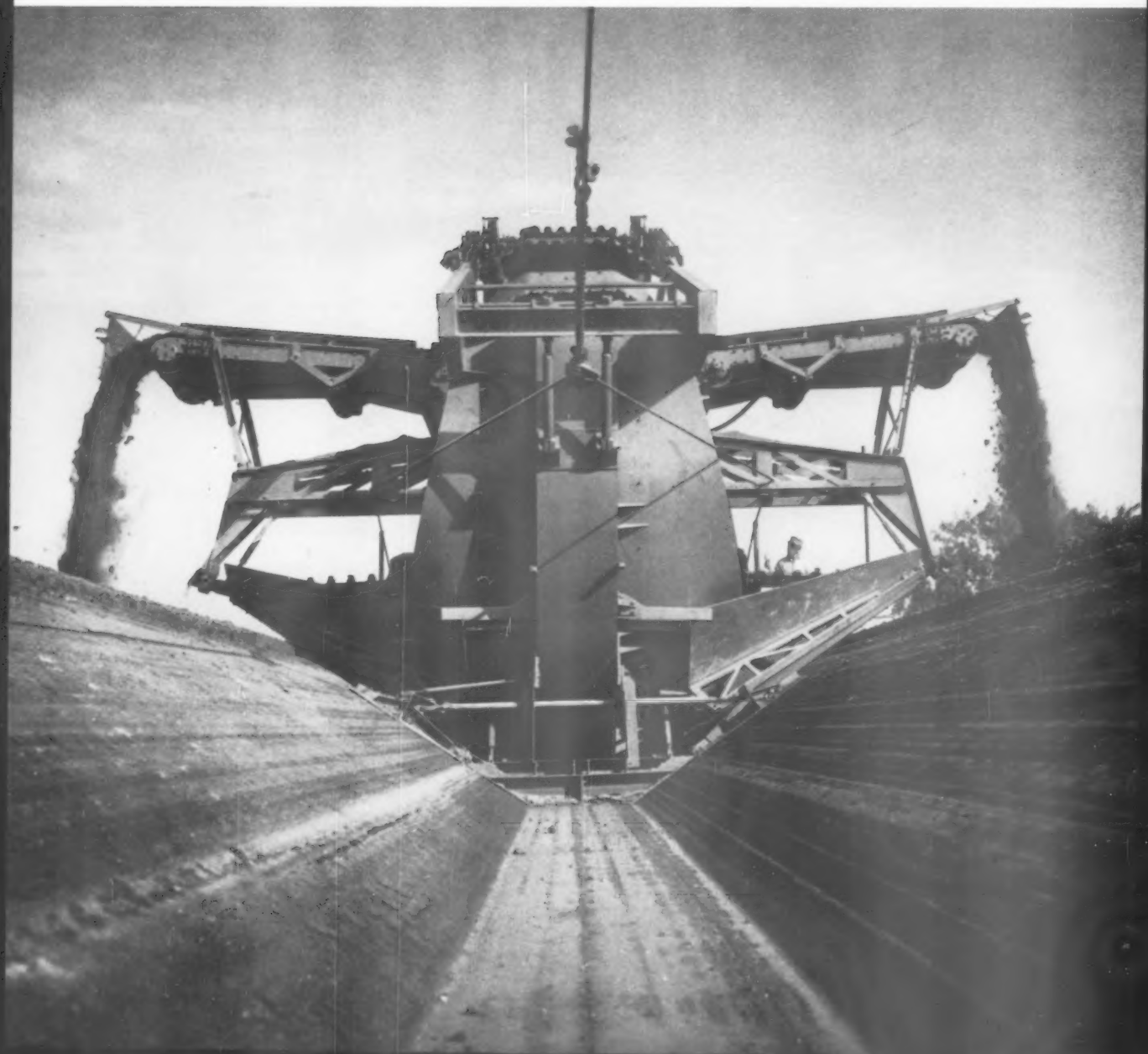
May 9–13, 1960. 2nd Southwestern Metal Congress and Exposition. State Fair Park and Sheraton, Dallas, Tex.

For details, circle No. 16 on Reader Information Card →

World's fastest ditching machine welded with M&T Murex electrodes

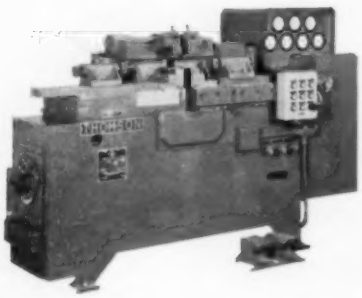
This monster machine carves out a continuous ditch 6′ deep, 4′ across at the bottom and 22′ across at the top, at the rate of 7′ a minute. Working at its top capacity of 800 cubic yards of earth an hour, the ditcher could keep a large fleet of dump trucks mighty busy. To give its all-welded frame superior rigidity for uniform digging, Gar Wood Industries used Murex electrodes – products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

MUREX
PRODUCTS FOR BETTER WELDING



Invented by
THOMSON
Perfected by
THOMSON
Resistance Welding
Spot • Projection • Seam
• Press • Flash-Butt
• High-Frequency

plus EXCLUSIVE
Synchro-matic and Synchro-shear*
... for jobs no other resistance welders can do



THOMSON QUALITY is so important that we build our own transformers to assure maximum performance and reliability. For all **AUTOMATED** and **HIGH-PRODUCTION** requirements — either special or standard design — **THOMSON QUALITY** is within your budget. A **THOMSON** quote will prove it.

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Look for our nearest representative in the yellow pages or contact —

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THOMSON ELECTRIC WELDER COMPANY
101 PLEASANT STREET, LYNN, MASSACHUSETTS
LYnn 2-7710

For details, circle No. 17 on Reader Information Card

Harris Calorific Forms Mexican Company

Clarence M. Taylor, president of the Harris Calorific Co. has announced, the formation of a new company to be known as Harris de Mexico, S. A., with general offices and manufacturing facilities in Mexico City, Mexico. The officers

Clarence M. Taylor

of the new company are Stevenson M. Taylor, president, David Champion, vice president, and Victor M. Hernandez, general manager.

All major Harris products in the gas welding and cutting field will be manufactured and distributed by this new company in Mexico. The manufacturing facilities include 20,000 sq ft of floor space with adequate ground area to permit future expansion.

Harris de Mexico currently is selling through three principal distributors who are Champion de Mexico, Gases Mexicanos and Casa Salazar. These companies have sales outlets in all major cities in Mexico.

Arcos Opens Warehouse

Arcos Corp., Philadelphia manufacturer of welding rods and electrodes, has moved from 123 S. Santa Fe Ave., Los Angeles, to a new warehouse-sales office building at 6222 Chalet Drive, Bell Gardens, Los Angeles, Calif.

The office will be staffed by Charles L. Godward, district manager, Norman S. Smith, salesman for the area and John J. Gorgas.

New Colmonoy Plant

A new plant for stainless alloy brazing and furnace heat processing has been opened in Dayton, Ohio, by the Stainless Processing Division of Wall Colmonoy Corp., according to Mr. R. L. Peaslee, vice president.

The plant at 5221 Webster St. houses high production pit-type furnace facilities which will handle parts up to 28 in. in diam by 35 in. high. The equipment is instrument controlled and used with pure, dry hydrogen atmosphere and other standard protective furnace atmospheres.

Plastic-design Lecture Series

A lecture series on the practical application of plastic design in one and two-story buildings was given at the Engineering Societies Building, New York City under the sponsorship of the American Institute of Steel Construction.

Six lectures were presented by R. Estes, Jr., research engineer for AISC, on consecutive Thursdays starting March 17, 1960. The course covered principles of plastic theory, methods of analysis, rules, design of continuous beams, design of single and multiple-span frames.

Distributor Named for P&H Line

Harnischfeger Corp., Milwaukee, Wis., has announced the appointment of Interstate Welding Sales Corp., Marinette, Wis., as distributor for the complete P&H line of welding equipment, covering the entire Upper Peninsula of Michigan. Interstate has been selling welding equipment in that territory for the past ten years, maintaining a branch in Marquette, Mich., and now plans to set up a stock point in Escanaba where P&H machines are made. Eugene Hart is Interstate's president.

Hobart Names Eight Firms

Hobart Brothers Co., Troy, Ohio, has appointed the following new distributors:

Livingston Oxygen & Equipment Co., Modesto, Calif.

Dakota Welding Supply Co., Inc., Watertown, S. D.

Lake Welding Supply Co., Muskegon, Mich.

Harold P. Elliott, Rapid City, S. D.

Gweco, Inc., New Orleans, La.

Hudson Valley Welding Supply, Inc., Poughkeepsie, N. Y.

Bartram & Johnson Co., Grand Junction, Colo.

Kessler Distributing Co., Richland, Iowa.

Chemetron's 25-year Club

Fifty-four veteran employees of Chemetron Corp. were given gold watches and welcomed into the company's 25-Year Club at recent dinners in Chicago and Louisville.

For details, circle No. 18 on Reader Information Card →

World's most efficient power plant depends on M&T Murex electrodes

To get more electricity than ever from a ton of fuel, Philadelphia Electric's 325,000-kilowatt Eddystone No. 1 generating station superheats steam to 1200°F, 5000 psi pressure. No other power plant equipment handles steam at such high steam conditions. In welding most of the pipe for Eddystone, The M. W. Kellogg Company used Murex electrodes – products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

MUREX
PRODUCTS FOR BETTER WELDING

Charles J. Haines, Chemetron president, presented watches and plaques to 50 employees of Chemetron, the National Cylinder Gas and Cardox divisions, and the Allbright-Nell Co., a subsidiary, at a dinner in Chicago's Pearson Hotel.

Four employees of the Tube Turns and Girdler Process Equipment divisions joined the club at the annual Louisville dinner at the Pendennis Club. John G. Seiler, Tube Turns president, presented the awards.

Ampco Expands

Two new distributors and a new West Coast plant are part of the expansion activities of Ampco Metal, Inc., Wisconsin producers of the Ampco line of electrodes and welding rods.

The new distributors are: District Oxygen Co., Inc., Brentwood, Md., and Welding Supply & Specialty Co., St. Paul, Minn.

The new plant, representing a 50% increase in floor space over the present Burbank location, will be located at the former A. O. Smith foundry, Huntington Park, Calif., in the Los Angeles area.

Newkirk Sales Wins Award

Newkirk Sales Co., Waterloo, Iowa, finished first among Hobart Brothers Co. distributors in 1959 "Quotabusters" sales contest. The company was cited by the Troy, Ohio, welding equipment manufacturer for attaining the largest percentage over quota of any Hobart distributor. Second place went to Valley Welding Supply, Appleton, Wis., and third to Marks Oxygen Co., Augusta, Ga.

RWMA Reports Increase

Members of the Resistance Welder Manufacturers Association received more than $3\frac{1}{4}$ million in new business during January, according to the monthly statistics compiled by the Association. This figure is the highest for one month in almost three years.

Orders received in January are 17% ahead of December business and reflect an increase of 36% over the same month last year. Shipments amounted to more than $1\frac{1}{2}$ million, 10% more than in January 1959. Backlogs at the end of January were reported in excess of $11\frac{1}{2}$ million, the highest in dollar value in nearly three years.

Amerloy Makes Debut

American Alloys Inc., a new manufacturer of automatic and cut alloy welding wire, has opened plant facilities at Newark, Calif., near San Francisco.

Edwin M. Westendarp

Edwin M. Westendarp [AWS], president, announced the firm has completed construction of a modern 15,000-sq ft plant building and is now making shipments to customers throughout the U. S.

The company's products include aluminum, stainless, magnesium, copper base and titanium alloy wires in spooled, coiled and cut lengths, and coated aluminum arc welding electrodes. Amerloy, Inc., is the Sales Division of American Alloys, Inc.

Electron-beam Technical Symposium

A technical symposium on electron-bombardment processes held at the Sheraton-Plaza Hotel in Boston on March 24–25, included a session on electron-beam welding. On Friday morning March 25th, three papers were read covering various aspects of the welding technique followed by a panel discussion on the subject lead by Carl Hartbower of the Watertown Arsenal. Copies of the proceedings are available at $5.00 from the sponsors, the Alloyd Corp., 35 Cambridge Parkway, Cambridge 42, Mass.

Thorne, Bach Promoted

National Electric Welding Machines Co., Bay City, Mich., has announced two promotions.

Paul Thorne [AWS], formerly chief electrical engineer, has been named chief electrical and development engineer. His new duties involve development of electronic applications in the building of automated

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World's thirstiest flood pumps welded with M&T Murex electrodes

Some of the biggest pumps in the world are controlling flood damage in Florida's Lake Okeechobee area. With intake pipes 12 feet in diameter, they suck up swimming pool sized gulps of flood waters every second, spew it out into a series of reservoirs. Though not yet complete, the system has already prevented an estimated $44-million damage. The thirteen Fairbanks-Morse pumps in use were welded with M&T Murex electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

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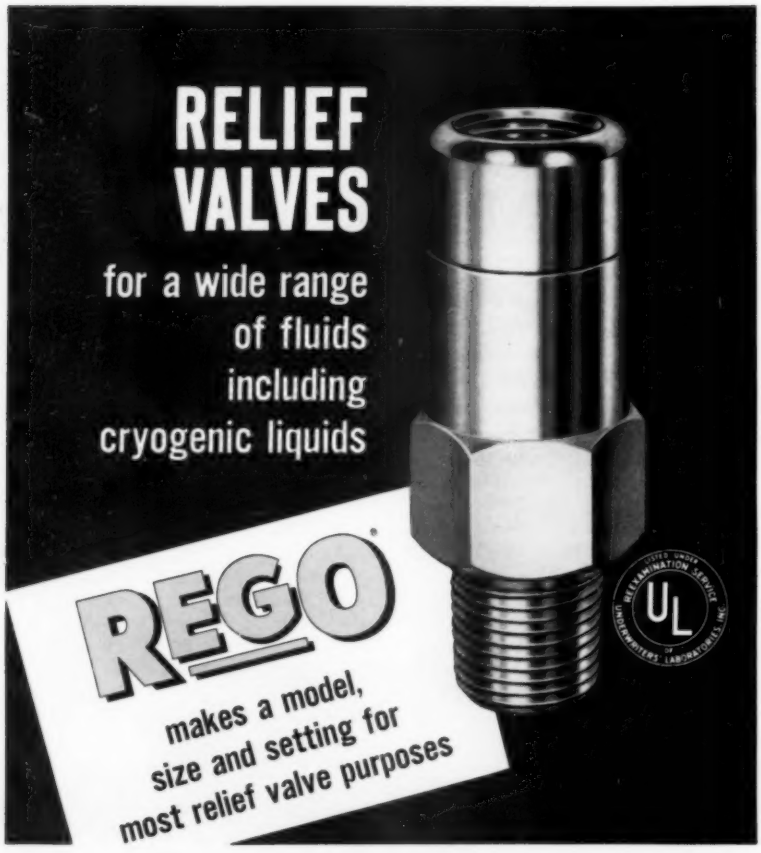
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welding machines. He will also be in charge of the laboratory and samples section.

Harold Bach (AWS), 20-yr veteran with the company and former manager of the service and research section, has been named chief welding engineer. Mr. Bach will remain in charge of service and test and has been made consultant liaison between engineering and test.

Progressive Welder Changes Name on 25th Anniversary

A consolidation of all Progressive Welder properties has been voted by the Board of Directors of that company. The new corporation will be known as Progressive Welder & Machine Co. with corporate offices at 3070 E. Outer Drive, Detroit, Mich. Personnel and facilities are the same as before.

The consolidation was accomplished upon the settlement of the estate of the late Fred H. Johnson, founder of the company and well-known pioneer in the resistance welding field.

Robotron Opens Canadian Unit

Robotron Corp., manufacturers of industrial electronic control systems, has announced the opening of a new subsidiary, Robotron of Canada, Ltd., at Sandwich West, near Windsor, Ont.

The Ontario plant, occupying 5000 sq ft on two and one-half acres of land, will produce Robotron controls and equipment to help meet the increasing demands of Canada's growing markets in the electronics and metalworking industries.

Ohio State Welding Course

A summer conference course covering the fundamental principles of welding engineering is announced by Ohio State University, Columbus, Ohio, for the period of June 13–24, 1960. The fee is $175 and applications are received by William L. Green, Department of Welding Engineering, 190 W. 19th St., Columbus 10, Ohio.

The 2-week program of instruction and practice will cover a complete range of techniques applicable in the major fields of construction and fabrication as well as theoretical background in metallurgy, processes and testing. A full range of laboratory equipment is available for welding, weld preparation and testing. Instruction will be by the well-known leaders, professors R. B. McCauley, R. C. McMaster and instructor W. L. Green. Sessions are for 8 hrs a day, 5 days a week.

ASM Metals Congress to Hold Welding Session

"New Frontiers in Welding and Brazing" will be the subject of a full half-day session of the 2nd Southwestern Metal Congress to be held by American Society for Metals, May 9–13 in Dallas.

Papers on this program will apply to the aircraft, rocket, space vehicle, electronics, petroleum and instrument industries in the 600-mile area surrounding Dallas and Fort Worth.

Numerous new developments in welding, brazing and cutting will be displayed in ASM's 2nd Southwestern Metal Exposition held concurrently with the Metal Congress.

Gregory Reports Earnings

Gregory Industries, Inc., manufacturer of Nelson stud welding products and Bulldog concrete fastening devices, today reported a 61% increase in net earnings for the nine months ended Jan. 31, 1960, which totaled $335,776 or 98 cents per share on 343,806 shares outstanding. This compares with net earnings of $207,496 in the comparable period last year, or 66 cents per share on the 312,656 shares then outstanding.

Sales increased 18% to a record high of $5,591,777 for the nine months, which compares with $4,739,259 in the comparable period a year ago.

Welsh Opens Warehouse

Welsh Manufacturing Co., Providence, R. I., manufacturer of industrial and welding safety products announces the opening of its new southwest warehouse at 142 Howell St., Dallas, Tex. Earl Mitterlener will be resident manager of this second Welsh regional warehouse.

National Electric Earnings

National Electric Welding Machines Co., Bay City, Mich., has reported first quarter earnings of $208,309 before taxes for the period ending Jan. 31, 1960.

E. C. Smith, company president, said the figure showed a gain of $361,792 over National Electric's position on the same date a year ago when a net loss of $153,483 was reported for the initial quarter.

In addition to the improved profit picture, Smith said, orders received by the company in the first 10 days of February totaled $1,401,000, increasing the company's backlog to $3,602,000. Work now in progress and on order is scheduled for delivery during 1960 and into 1961.

LARGEST HOBART DISTRIBUTOR

Sales volume award for 1959 is presented to Frank Smith, manager of Ray Smith Co., Detroit, by E. A. Hobart (left) and W. H. Hobart (right) president and vice president, respectively, of Hobart Brothers Co., Troy, Ohio

Oxygen Storage Plant

A new transfilling plant to serve the Jacksonville, Fla., area with liquid and gaseous oxygen for industrial and medical purposes has been placed in operation by National Cylinder Gas Division of Chemetron Corp.

The new facility receives liquid oxygen from large production centers by rail and stores it. Oxygen then is delivered to customers in liquid or in gaseous form.

Bronze Welding Rods from Start to Finish

Volume production of a complete line of industry-vital bronze welding rod, believed to be an industrial "first" for the 13-state West including Alaska and Hawaii, is under way in the western headquarters plant of Titan Metal Manufacturing Co., Division of Cerro de Pasco Corp., Newark, Calif.

Last steps in the cycle of bronze welding rod production at the Titan Metal Mfg. Co.

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PERSONNEL

Frank J. Mooney Honored by N.A.E.M.

Frank J. Mooney, convention manager of AWS, has been selected as the 1960 chairman of the New York group of the National Association of Exhibit Managers, Inc. This organization is devoted to the "advancement of expositions and dissemination of knowledge and information thereof."

Mr. Mooney has been on the staff of the AMERICAN WELDING SOCIETY for 13 years and has been responsible for the organization of the SOCIETY'S annual conventions and meetings. He was educated at Manhattan College, graduating with a Bachelor's Degree in Business Administration.

Greenberg Named Director of Engineering and Training

Appointment of Simon A. Greenberg as director of engineering and training services for Eutectic Welding Alloys Corp., Flushing, N. Y., was announced recently. An internationally known welding authority, Mr. Greenberg was national technical secretary of the AMERICAN WELDING SOCIETY for 15 years. In his new post he will "head a drive for the most money-saving use of welding in maintenance and repair," according to Rene D. Wasserman, Eutectic president.

Mr. Greenberg's extensive background includes editorship of the third edition of the WELDING HANDBOOK and contributions on welding to many other reference works. He has served on technical committees of the ASTM, ASA and other technical groups. He has held committee and advisory posts with the Army Ordnance Department of the Department of Defense, Department of Commerce Welding Industry Advisory Committee, Organization for European Economic Cooperation and the International Institute of Welding.

Brown Appointed Manager

The appointment of Robert T. Brown AWS as manager of the Welding Division, Metal & Thermit Corp. has been announced by H. E. Martin, president. He replaces A. J. Fisher, Jr., who was recently named executive vice president of M&T. Mr. Brown was sales manager of the Welding Division. His new responsibilities also include research and production of welding machines, electrodes and accessories.

Mr. Brown joined M&T in 1943, when he organized the compnay's personnel department. He subsequently was given research and development responsibilities for M&T's Thermit operations in Jersey City. Following technical service assignments on thermit welding and electrodes, he became regional manager at Newark, N. J., and then Pittsburgh. In 1954 he was appointed sales manager of the Welding Division. He received his degree in Mechanical Engineering from Columbia University in 1933.

Robert T. Brown

Wayne R. Wilcox

Matthew Waite

Frank J. Mooney

Simon A. Greenberg

Warren Smith

Undersea nest for a talented metal bird

This is the firing tube of the Navy's Polaris missile, made by Consolidated Welding and Engineering Company, Chicago, Ill. Every weld must be flawless. To make sure, more than 100 radiographs are made on each assembly.

Made of HY-80 plate with monel inserts, this firing tube presents difficult problems in welding dissimilar metals. But radiography, with Kodak Industrial X-ray Film, Type AA, checks the entire assembly for discontinuities.

Radiography provides the means of "seeing" internal conditions and supplies a lasting record of what is seen. It gives producers of welded products and of castings a means of making sure only high-quality work is delivered.

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Radiograph of weld on missile firing tube.

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Breakspear Appointed

Omark Industries Ltd. Guelph, Ontario, announce the appointment of Frank Breakspear AWS as product manager for the Omark stud welding system, a new product recently added to the Omark Fastening Division.

Frank Breakspear

Before coming to Canada, he acquired wide experience as a specialist in all types of welding techniques. He taught welding science and metallurgy and later operated his own consultant firm. Prior to joining Omark, Mr. Breakspear was employed in the aircraft industry.

Bull and Hale Transferred

G. N. Bull has been named district manager of a new sales engineering district established in Florida by the Lincoln Electric Co., Cleveland, Ohio. Mr. Bull is moving to Miami from New York where he has been district manager since 1926. The office location is 3455 N. W. 54th St., Miami, Fla.

Russell S. Hale AWS has been named district manager of the Boston engineering district. Mr. Hale formerly was district manager in Albany.

Mr. Hale, a graduate of the University of Nebraska with an E.E. degree, was employed by Lincoln Electric in 1950 and spent seven years as a field engineer in the Chicago office until his appointment to district manager in Albany in 1957.

McNally, Waite and Wilcox Become Managers

Arcos Corp., Philadelphia manufacturer of welding rods and electrodes, has named product sales and service managers for three of its product groups.

Wayne L. Wilcox AWS, former field engineer for Arcos, is product manager for stainless, low- and high-alloy welding. The products involved are covered electrodes, filler wires and fluxes; EB consumable inserts and equipment for semiautomatic and automatic welding of stainless.

James McNally is available for technical help in the semiautomatic, automatic CO_2 and submerged-arc welding of mild steel. He will cover wire drive equipment, flux-cored wire, mild-steel filler wire and flux.

Matthew Waite AWS is responsible for technical help in the welding of aluminum, magnesium and reactive metals. In addition, his activities will involve titanium and other reactive metals as well as wire-drive equipment for welding aluminum.

Surmacz, Drewery and Over Advance

A new plant manager and two other appointments have just been announced by Harnischfeger Corp. in West Milwaukee.

The new plant manager is Joseph Surmacz who joined the firm in 1951 as chief industrial engineer, being largely responsible for a

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A recently developed system for ultrasonic inspecting and recording the welds on solid propellant chambers for Aerojet-General Sacramento, California

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new standard hour incentive system. He is a graduate of the Carnegie Institute of Technology.

David Drewery was appointed director of production and industrial engineering. He also joined the firm in 1951 and is a graduate of the Carnegie Institute.

The third appointment named Robert Over as superintendent of machine shops, heat treat, salvage and cut off departments. Mr. Over joined Harnischfeger in 1942. He attended the Illinois Institute of Technology in Chicago and also the Student Foreman Training Program of International Harvester.

EMPLOYMENT SERVICE BULLETIN

Position Vacant

Welding Engineer sought, engineering degree required. An opportunity for a challenging position in teaching engineers welding is available at California State Polytechnic College, Pomona, California. Interested men are invited to contact the Dean of Engineering.

Services Available

A-730. Interested in a position as a welding inspector or as a sales representative of welding equipment or in a supervisory position. Can travel anywhere. 24 years experience in welding industry.

A-731. Welding Engineer with practical and formal education desires responsible position in either sales, engineering or production. Mechanical Engineering Degree; 7 years practical experience, 5 years engineering and sales representative in development and manufacturing problems, 4 years sales engineer in automatic arc-welding machine manufacture. Experienced with inert-arc processes—automatic and manual, all oxyacetylene processes, electric welding, ferrous and nonferrous metals. Age 39. Married. All replies answered.

A-732. Welding Engineer, Welding Specialist or Welding Technician. Can operate and instruct personnel in uses of all welding processes on ferrous and nonferrous metals. Familiar with code requirements and certification of operators; military and commercial weldments. Also uses of nondestructive processes for testing and checking weldments. Can write and setup welding procedures. Twenty-five years technical and practical experience in welding industry.

WELDING RESEARCH ENGINEER

A progressive leader in the alloy welding field requires the service of an experienced engineer in formulating alloy electrode coatings. Additional experience with materials used in automatic and semi-automatic processes desirable.

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WELDING JOURNAL

WELDING ENGINEER

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HELP WANTED **WELDING ENGINEER**

The General Electric Company is seeking a qualified Welding Engineer to join the staff of its Materials and Processes Laboratory, located in Erie, Pennsylvania. An outstanding career opportunity, this position offers an excellent professional working climate that includes active collaboration with others in the fields of metallurgy and mechanical engineering.

Basic duties: Applied research, development, and application work in materials, processes, equipment, and welding design considerations involved in locomotive and car equipment design and manufacture.

Qualifications: B.S. in mechanical engineering and/or metallurgy and a minimum of five years of experience in welding engineering. Candidate should be knowledgeable in both the welding and mechanical engineering fields.

Qualified applicants will be invited to inspect laboratory facilities and plant at Company expense. Relocation expense assistance will be provided. Additional information about General Electric's extensive program of Company benefits for employees and dependents is available upon request.

If you meet our qualifications and if you would like to join a Company whose expenditures for research and development are well over three times the average for all industry, send your resume in confidence to: SJ-534

Dr. C. A. Burkhard, Manager
Materials and Processes Laboratory
Locomotive and Car Equipment Department
General Electric Company
Erie, Pennsylvania

GENERAL ELECTRIC

Abstracts of Current PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,909,649—Out-of-position Arc Welding—George G. Landis, South Euclid, Kenneth L. Brown, Garfield Heights, and Walter G. Mosgrove, Willoughby, Ohio, assignors to the Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

A method of arc welding a circular bead onto a round workpiece is covered in this patent. The workpiece is rotated about a horizontal axis and an electrode is advanced lengthwise at an angle below perpendicular to the workpiece. The electrode is energized so that the electrode metal is moved to the workpiece in the form of a fine spray. The workpiece is rotated at a speed so that the energy input to the workpiece is in the region of 10,000 joules per inch of weld.

2,909,778—Method and Means for Bare-electrode Welding—George G. Landis, South Euclid, and Donald M. Patton, Willowick, Ohio, assignors to the Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

In this patent to Landis and Patton a method of electric-arc welding is disclosed wherein one or more killing agents selected from a listed class of materials is fed into the arc in a sufficient amount that the iron oxide in the weld pool will be reduced by the killing agent in preference to the carbon. The killing-agent protector is also fed into the arc in such an amount as to protect the killing agents from the oxygen and nitrogen of the atmosphere.

2,910,572—Apparatus for Welding a Joint—Charles Diehl, Ridgefield, N. J., assignor to the M. W. Kellogg Co., Jersey City, N. J., a corporation of Delaware.

The patented apparatus relates to a workpiece including a pair of aligned tubular sections having their facing ends shaped into the component parts of a welding groove adapted to be positioned in close abutting relation for welding a joint therebetween. Diaphragm means are present within each of the tubular sections to form a closed chamber encircled by the abutted ends. Other means supply gas at a positive pressure to the chamber. Orifice means are provided for controlled venting of the gas in the chamber to the atmosphere. Means also are present to indicate the gas pressure within the chamber.

2,910,640—Method and Apparatus for Welding—John H. Blankenbuehler, Troy, Ohio, assignor to the Hobart Brothers Co., Troy, Ohio, a corporation of Ohio.

A novel welding transformer is disclosed by the present patent and it includes a pair of transformer core means each having a primary and secondary winding thereon. A pair of parallel leakage-path means is associated with each of the transformer cores for carrying a portion of the main flux of the transformer. Each of such leakage-path means includes an air gap so that such means are relatively ineffective when the transformer is under no load but become increasingly effective as the load is increased. Electromagnetic-control means also are present and extend between the parallel leakage paths to vary the degree of saturation of such path means. Other means are present to supply direct current to the electromagnet-control means. Both the primaries and secondaries of the transformers are connected in T and the primaries of the transformer-core means are energized from a three-phase power supply line.

2,910,660—Welding Transformers—Ronald Frederick Brennen and James Arthur Bucci, Brooklyn, N. Y., assignors to Welding Industry Research and Patent Corp., a corporation of New York.

In the patented transformers, an annular toroidal core is provided and a primary winding is immovably secured thereto. A secondary winding embraces the core and is movable therealong in an arcuate path having an axis coinciding with the axis of the core. The transformer also includes mechanical means to move the secondary along the core and hold it in a given position with relation to the annular core.

2,911,298—Copper-base Brazing Alloy—Thomas L. Woolard, Wellsville, N. Y., assignor to the Air Preheater Corp., New York, N. Y., a corporation of New York.

Woolard's novel brazing alloy consists of about 70 to 90% copper, 9 to 27% nickel and about 1 to 3% phosphorus.

2,911,515—Narrow Lap-seam Welding Machine—Joseph H. Cooper, Warren, Ohio, assignor to the Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

Cooper's patent relates to a welder of the type where adjacent ends of strips to be welded are positioned and are traversed by welding means. The welder includes a housinghaving an opening therein for reception of the welding means, and the patent particularly relates to the provision of a special vertically movable upper and lower shear-carrier member received in the housing above and below the path of the strip travel. Special means are provided for control of these shear-carrier members to control movement thereof and of an associated upper shear carriage.

2,911,516—Welding Machine for Rails or the Like—Earle F. Cox, Chicago Heights, Ill.

Cox's patent relates to a clamp mechanism for use in butt welding rails or similar objects together. The clamp mechanism provides means therein for moving one of the rails transversely with relation to the other rail to aid in properly aligning and positioning the members to be butt welded.

2,911,517—Twin-electrode Welding Method and Apparatus—Frank W. Armstrong, Barberton, Ohio, assignor to the Babcock & Wilcox Co., New York, N. Y., a corporation of Delaware.

This patent relates to a method of fusible metal-arc welding including the step of juxtaposing a pair of fusible metal electrodes and a conductive metal workpiece on which metal is to be deposited. The first electrode is connected to the negative terminal of the first source of substantially constant direct-current potential. The second electrode is connected to the positive terminal of a second source of substantially constant direct-current potential. A positive terminal of the first source and the negative terminal of the second source are connected to the workpiece. Arcs are established between each of the electrodes and the workpiece and the electrodes are fed toward the workpiece as metal is fused from the arcing ends of the electrodes, which feeding is at speeds such that the current flow through the common junction is substantially zero.

2,911,581—Three-phase to Single-phase Welding Method and Machine—Stuart C. Rockafellow, assignor to Robotron Corp., Detroit, Mich.

Rockafellow's welding process relates to supplying single-phase low-frequency alternating current from a relatively high-frequency poly-phase alternating-current source to a load transformer and the process includes the steps of rectifying the current from the source and successively delivering pulses of the current of opposite polarity to the primary winding of the transformer. These pulses are delivered at timed intervals to permit decay of the flux within the transformer during the intervals. The process includes counting pulses from all of the phases of the source and, after a desired number of pulses, terminating the delivery of the current pulse of one polarity to the transformer, and after further count of pulses, initiating the delivery of a current pulse of opposite polarity to the transformer, which last-mentioned current pulse may be initiated from any selected phase of the current source.

2,912,549—Induction Welding of Tubes—Thomas P. Dunn, Rome, N. Y., assignor to Revere Copper and Brass, Inc., New York, N. Y., a corporation of Maryland.

The present patent relates to apparatus for welding a longitudinally open seam in a tubular shape of weldable material. The tubular shape is progressively advanced through the weld zone where the edge portions of the seam are heated by an induced electric current to welding temperature and the heated edges are forced together by pressure rolls to effect the weld. An induction coil is positioned around the tubular shape at the welding zone to induce in the tubular shape a circumferentially flowing electric current. An inside scarfing-tool assembly including a non-magnetic coolant conduit is anchored inside the tubular shape in advance of the welding zone to deliver a coolant to the scarfing tool. A generally cylindrical permeable magnetic member is mounted in the coolant conduit within the influence of the magnetic field of the coil so that coolant can flow around the magnetic member.

2,912,563—Apparatus for Welding and Cutting of Sheet Metal—Willy H. Schlieker, Meerebusch, near Dusseldorf, Friedrich Kunz, Wuppertal-Elberfield, and Wilhelm Pletsch, Velbert, Germany, assignors to Firm Walzwerk Neviges, Willy H. Schlieker & Co., Neviges, Rhineland, Germany.

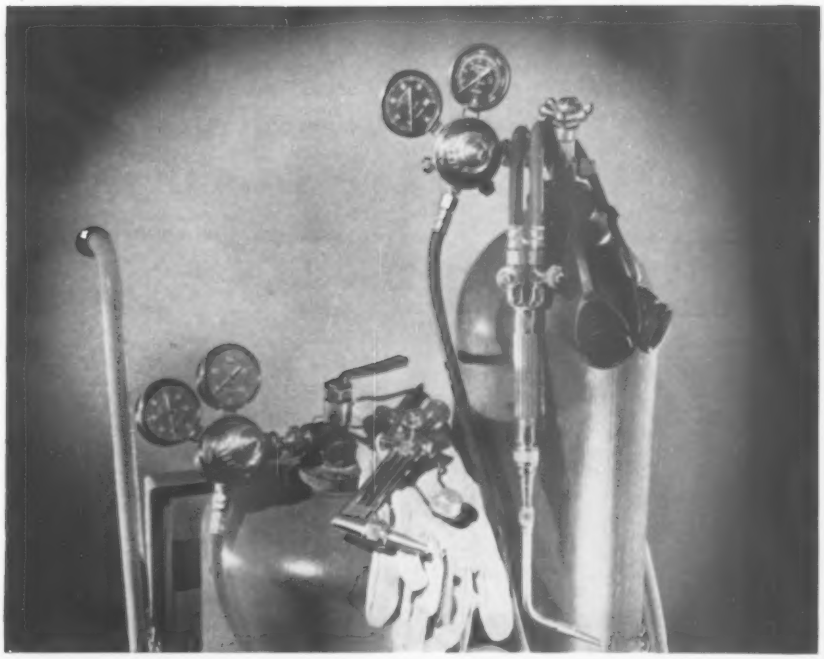
The present patent is on apparatus for producing sheet metal which is processed in strip form and thereafter cut into desired lengths. A multiple spot welder is present for welding metal sheets end-to-end in overlapping series arrangement for forming a strip. The operation of the welder corresponds to the speed of the passage of the sheets in strip form through the heat treating unit. Cutting means are associated with the apparatus to cut the strip to desired lengths.

2,912,564—Resilient Lost-motion Device for Welding Apparatus and the Like—James F. Deffenbaugh and Irving R. Taylor, Warren, Ohio, assignors to the Federal Machine & Welder Co.

This patent is on a movable electrode assembly for a low-inertia resistance welding machine having quick follow-up characteristics and comprises special electrode support means to aid in urging the electrode against a receding work surface when the latter is softened by a welding current.

2,912,565—Automatic Safety Control for Automatic Machinery—Harold S. Lund, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

Lund's apparatus is on a control for a fabrication line having automatic transfer means to move a workpiece to and from an arc welding machine. The control includes means to normally maintain the electrode in spaced relation to the workpiece and disconnect means to stop the arc welding machine. Other control means are provided responsive to a short circuit of the electrode to the work to stop operation of the transfer line when the electrode engages the work and further means responsive to operation of the welding machine are present to hold the control means inoperative and to release such control means in response to actuation of the disconnect means.



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Current Welding LITERATURE

For copies of articles, write directly to publications in which they appear. A list of addresses is available on request.

Carbon-dioxide Welding

Effect of Oxygen Additions to CO_2-shielded Metal Arc. A. A. Smith. *Brit. Welding J.*, vol. 7, no. 1 (Jan. 1960), pp. 15–19.

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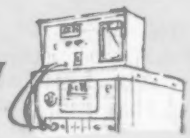

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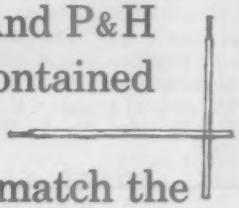

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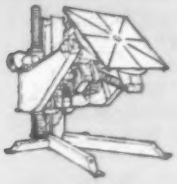

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New Literature

AWS Publishes Book on Gas-shielded Arc Welding

The first AWS book on gas-shielded arc-welding processes is announced by the AMERICAN WELDING SOCIETY. It contains 78 pages, 39 illustrations and 9 tables.

The contents are taken from published and unpublished material from Sections I, II and III of the Fourth Edition of the Welding Handbook. Included in this small, authoritative book are: gas-shielded tungsten-arc welding, gas-shielded metal-arc welding (including CO_2 welding), cutting, gases, equipment and cost data. The book is profusely illustrated and photographs, schematic diagrams or charts show every step of the way.

Gas-Shielded Arc Welding is currently being used as a text for an intensive course on the subject presented by the AMERICAN WELDING SOCIETY. "There is a great need for information on the latest welding developments and techniques," stated Fred L. Plummer, National Secretary of the SOCIETY, "in order that industry may profit by the use of the most economical and productive fabrication methods. This concise, authoritative book, upon a relatively new welding process, will prove an invaluable guide to all users of these processes."

Copies may be obtained from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N.Y. Price $1.50.

Welding Electrode Catalog

A comprehensive welding electrode catalog published by Hobart Brothers Co., Troy, Ohio, is available at no charge. It covers the manufacturer's complete line of welding electrodes, gas welding rod, nonconsumable electrodes, submerged arc welding flux and automatic welding wire.

A technical section of the catalog offers helpful information such as explanation of AWS classification numbers; mechanical properties terms (defined); color codes; 8 factors to consider in selecting welding electrodes; electrode approvals, specifications and classifications; typical deposition rates; and size and number of pieces per pound.

For your free copy, circle No. 51 on Reader Information Card.

Flame-plated Coatings

The Linde Co., Div. of Union Carbide Corp., 1245 Main St., Speedway, Indianapolis 24, Ind., has a 4-page brochure describing the methods, qualities and uses of their flame-plating process. Thin coatings are achieved of carbides and oxides which are wear and corrosion resistant. The controlled detonation process is said to result in a strong bond. Physical properties of various coatings are tabulated.

For your free copy, circle No. 52 on Reader Information Card.

Electrode Data Sheets

New electrode data sheets for "Sureweld" a-c and d-c electrodes are available from National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill. The seven sheets include four for electrodes used in mild-steel welding, one for medium-carbon steel, one for high-carbon steel, and one for railwear.

Welding characteristics, recommended current ranges, welding or surfacing procedures and the physical properties of deposited metal are given. Also described are typical applications of each electrode.

For your free copy, circle No. 64 on Reader Information Card.

Buyer's Guide

A "Buyers' Guide to Nickel Alloy Steels Stocked by Steel Service Centers" has been issued by The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y. The booklet describes the range of nickel-alloy-steel compositions and forms generally available through steel service centers throughout the country.

The 27-page booklet is divided into two sections. Part I lists the steel service centers and their nickel-steel stocks alphabetically by States. Part II lists the nickel alloy steels (by AISI number when available) and the respective steel service centers supplying them.

For your free copy, circle No. 53 on Reader Information Card.

Guide to Aluminum Alloys

A guide to the selection of aluminum alloys is offered by the Metals Division of Olin Mathieson Chemical Corp., 400 Park Ave., New York 22, N. Y.

The 24-page booklet, "Olin Aluminum Mill Products," describes the physical properties, fabrication characteristics and economic advantages of a wide variety of aluminum sheet, plate, rod, bar, extrusion and casting alloys.

Information on such diverse subjects as specialty sheet products, bus conductor, mine and oil country pipe, architectural shapes and the efficient storage of rod and bar, is included.

For your free copy, circle No. 54 on Reader Information Card.

Pipe Fluoroscopy

A 9-page panel session report titled "A Progress Report on Continuous Fluoroscopic Inspection of Submerged-arc Welded Line Pipe" is available from Philips Electronic Instruments, 750 S. Fulton Ave., Mount Vernon, N. Y.

Illustrated with photos, radiographs and drawings, the booklet discusses limitations and advantages of conventional fluoroscopy, basic principles, preliminary investigations, pilot installation, production unit and fluoroscopic standards for mill control of weld quality. A schematic plant layout for the fluoroscopic unit is included.

For your free copy, circle No. 55 on Reader Information Card.

RWMA Describes Service

A folder describing the various services performed by the RWMA for industry and for its members is available. Included is an order form listing 21 publications. Both can be obtained by writing to headquarters, 1900 Arch St., Philadelphia 3, Pa.

Induction-heating Equipment

A folder on induction-heating equipment for automated metal heating has been published by Robotron Corp., Detroit, Mich., manufacturers of industrial electronic controls. It explains technical services available to customers—problem analysis, research, design engineering and manufacture of tailor-made end product—with illustrations of facilities and equipment to do the job.

Also illustrated and described are some of Robotron's standard induction heating units.

For your free copy, circle No. 56 on Reader Infomation Card.

Refractory Metals

"Fansteel Metallurgy," a 4-page journal of information on the refractory metals, contains an article by J. T. Stacy of Boeing Airplane Co., Seattle, Wash., on the use of columbium alloys. Published by Fansteel Metallurgical Corp., North Chicago, Ill.

For your free copy, circle No. 57 on Reader Information Card.

Basic Guide Reprint

A reprint on heavier paper of "Basic Guide to Ferrous Metallurgy," an $8^1/_2 \times 11$-in., 4-color wall chart is offered by Tempil® Corp., 132 W. 22nd St., New York 11, N. Y. The guide illustrates the metallurgical zones of carbon steel throughout the heat ranges from solid to liquid.

For your free copy, circle No. 58 on Reader Information Card.

Steel-making Progress

"Review," a 39-page pamphlet (vol. 2, no. 21) published by Murex Ltd., Rainham, Essex, England, presents a brief survey of steelmaking for the nonspecialist. The history of the Bessemer process and related methods of modern Continental steel making which employ pure oxygen are briefly discussed.

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If you're bothered by large voltage drops, it will pay you to investigate the *Load Control System*.

Load control is the automatic programming of line loading in welding systems to give maximum power utilization without production loss or excessive voltage drop.

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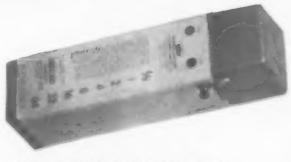

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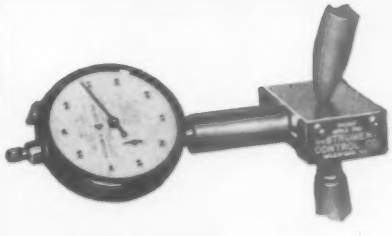
Counts actual weld time during firing. PORTA-COUNT is light and small enough to carry easily—keep right on the job. Completely portable and self-contained with long life (up to 2 years) batteries. Counts single phase.



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with only 5/8" between load points. Rugged all mechanical design—no leaky hydraulic units or sensitive electrical circuits to cause trouble.

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Linde SIGMATIC Welders

SWM-13 cart-mounted unit with separate control cabinet rolls readily over hoses, minor obstacles, slings easily from adjustable handles.

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for All Mig Welding Jobs

SWM-11 features compact mounting of wire feed unit and wire spool on angular welded steel structure; combination continuous-fusion and spot-welding unit, SWM-11-S, is also offered.

LINDE's new "Sigmatic" line gives you the most adaptable and versatile mig welding equipment available today. With one of these units, you can weld virtually any metal, in almost any thickness. You can use wire from .020 in. to 3/32 in. diameter (including cored wire) and any shielding gas you select.

Versatility is engineered into the "Sigmatic" line. On the SWM-11, you can change from horizontal to vertical wire feed in minutes. With any unit, you can use conventional "spray-arc" or the LINDE "short-arc" process which has proved so successful on thin steels. Dual-purpose units are available which handle both spot welding and continuous fusion welding.

Several styles of torches are available, ranging up to 500-ampere capacity. Control cabinets are designed and wired for maximum ease of service and for internal addition of special operating features selected to fit *your* needs.

The same development and laboratory facilities that planned and built this equipment are available for help in applying it to your welding problems. For information on a demonstration see your LINDE representative. Or write for catalog F-1372, Dept. WJ-05, Linde Company, 270 Park Avenue, New York 17, N. Y.

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Welding Equipment Catalog

A colorful 28-page catalog published by Sellstrom Manufacturing Co., Palatine, Ill., featuring the com-

plete line of eye and face protection equipment, gives fully illustrated descriptions on all goggles, glasses, helmets, face shields, lenses, respirators and other products.

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Plant Survey Bulletin

Airline Welding and Engineering, 15899 S. San Pedro St., Gardena, Calif., a company established in 1952, has issued bulletin No. 5-9-58 which describes specialized equipment developed to handle high-precision components and difficult-to-weld materials required by the aircraft and missiles industries. The bulletin also reveals some of the production techniques employed as well as the shop range and capacity.

For your free copy, circle No. 61 on Reader Information Card.

Water Control

A circular describes Model ES-20, "Water Mizer" control which is designed for use on welding equipment where condensation is a problem. By using two solenoid valves and delayed time relay, in conjunction with thermostats, water-flow control is obtained. The manufacturer is Van Vooren Products, 2133 9th St., East Moline, Ill.

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EJC Newspaper

"Engineer," vol. 1, no. 1, a news sheet published on behalf of engineers and engineering by Engineers Joint Council made its initial appearance in March. The EJC is an association of 21 engineering societies, including AWS.

For your free copy, circle No. 63 on Reader Information Card.

REVIEWS OF NEW BOOKS

Engineering Manufacturing Methods by Gilbert S. Schaller, McGraw-Hill Book Co., New York, 1959, 682 pp., price $9.50.

This second edition of the book has been extensively revised to keep pace with the rapidly changing developments in manufacturing techniques, and in this respect has several unique contributions. The numerous illustrations have been brought up to date. Problem questions at the end of each chapter are completely new.

The author, professor of mechanical engineering at the University of Washington, has divided 36 chapters into 5 main sections covering: materials in manufacturing, foundry practice, shaping and treating, machining, and welding. The 7 chapters devoted to welding present a comprehensive survey of the history, basic concepts and operational details of the entire field. An interesting description is given of flame bending and straightening.

●

Foreign Books. Reviews obtained from foreign periodicals by Gerard E. Claussen, contributor of World-Wide Welding News.

Manual Welding Technique (Précis de la Technique du Soudage,) by C. G. Keel, 242 pages, published by Association Suisse Pour La Technique Du Soudage, Basel, Switzerland, 1959, 12 Swiss francs (about $3.50).

Dr. Keel, the editor of the Swiss Welding Society's journal, wrote this book as an aid to students of the Society's school for welding operators. Welder qualification in Switzerland is in accordance with Swiss Standard VSM14061 of the Swiss Machinery Builder's Society, who recommend the book. The Standard calls not only for a series of welds, but also for an oral examination. The oral examiner determines if the operator possesses sufficient professional knowledge to guarantee conscientious, qualified work. The examination covers metallurgy of steel, selection of filler metal and the details of gas and arc welding.

The book covers the topics of the examination, which really embraces all manual welding technology for mild steel with admirable simplicity. The original book was published in the German language in 1958.

Introduction to the Fabrication of Polyvinylchloride (Einführung in die Verarbeitung PVC) by A. Moretti and R. Hinden, 74 pages, published by Verlag Aargauer Tagblatt AG., Aarau, Switzerland, 1958.

Since 1956 the Swiss Welding Society has conducted courses in Basel on the welding of plastics. The instructor and an editor of a technical journal collaborated in making this a most outstanding practical textbook. The book conveys its information more by charts and photographs, most of them in color, than by words. The instruction starts with the properties of PVC and the construction of hot-air torches, and continues through the procedures for joining plates and piping.

The Effect of Preheat on Internal Stresses in Flame Hardened Parts (Die Wirkung Einer Vorwärmung Auf Die Eigenspannungen Dei Oberflachenhärtung Mit Flammen) by H. Buhler, Band 13 Heft 2 of Harterei-Technische Mitteilungen, pages 115–131 (1959). Deva Fachverlag, Stuttgart, Germany.

Measurements were made of internal stresses in shafts $1^{5}/_{8}$ and $2^{1}/_{4}$ in., 6 to 7-in. long of three plain carbon steels with 0.48, 0.50 and 0.72% C after flame hardening by the spinning process. Several combinations of travel speed, depth of hardening and preheating temperature (up to 930° F) were investigated. The surface stresses always were compressive. Under certain conditions preheating in a furnace or with a torch reduced the tensile internal stresses at the center of the shaft below dangerous levels.

High Production Welding Processes (*Hochleistungsfähige Schweissverfahren*) by Werner Gunther, 69 pages, published by VEB Carl Marhold Verlag, Halle (Saale) East Germany, 1959, 3 marks.

The two processes discussed in this booklet No. 5 of the East German Central Institute of Welding are submerged melt and electroslag welding. The former occupies most of the book and is a helpful operator's handbook. Both fully automatic and squirt-gun equipment is discussed. Tables of welding condition for butt and fillet welds are given. The unbeveled butt and bare wire without copper coating are two items that are favored in the book. Electroslag welding is given only cursory treatment.

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New Products

Cast-Iron Welding

A 3-step process for arc welding cast iron in much shorter time than heretofore has been announced by Eutectic Welding Alloys Corp., 40–40 172nd St., Flushing, N. Y.

The "Quenchweld" process consists in grooving out the joint with an electrode called ChamferTrode,

Each filler-bead is quenched immediately after welding

Completed repair is now ready for machining

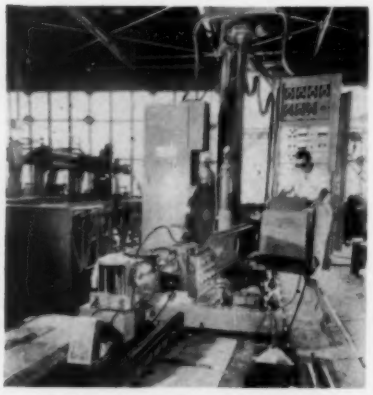
sealing off the groove with a thin deposit using "Eutectrode 27" and, finally, completing the weld using "Quenchtrode 24." The sequence is said to obviate the disadvantages of other methods but in addition it affords a great saving of time in that the filler passes may be immediately water quenched.

Both the method and the result are reported to extend the range of possible cast-iron welding repair. The process is said to be usable with any cast iron except chilled iron, Ni-Hard, and similar materials which would themselves crack during the quenching.

For details, circle No. 101 on Reader Information Card.

Welding Manipulator Embodies High-quality Control

Sciaky Bros., Inc., 4915 W. 67th St., Chicago 38, Ill., have announced the production of a boom-type automatic welding machine having unusually versatile capabilities. Incorporating all the usual features of this type of machine together with some not commonly found, the product takes a new step forward with the addition of several exclusive innovations. The machines were built for North American Aviation, Los Angeles Division and eventually will be used in the B-70 Intercontinental Bomber program.



Special features of manipulator

Especially suited to gas-shielded welding, the machine uses both gas tungsten-arc and gas metal-arc welding.

The boom has a welding reach of 12 ft in horizontal extension and can rotate a complete circle through a vertical rise of 10 ft. In addition the welding head is mounted on a powered face plate which provides 360-deg motion in a vertical plane. Another directional-control feature is the fine horizontal and vertical feeds on the torch-face plate. Added to this is arc-length control through a proximity tranducer system. All of the position controls used while welding employ Sciaky's "Zero-Error" electronic motor-control circuit. This circuit reportedly achieves an acceleration response from zero speed to any preset speed within 5 cycles using 60 cycle power. Deceleration and reversal are obtained within 3 cycles.

A further refinement is an automatic seam-tracking device which employs a sensing circuit that keeps the electrode at the joint of a migrating seam. In addition a newly devised d-c power source also employs a feed-back system to insure constant circuit characteristics at the arc. To enable an operator to monitor all this, a closed circuit TV is located at the main control console. Miniaturization of the welding head component makes possible the internal welding of cylinders 20 in. in diam. Automatic step welding is achieved by having a second control box preset for welding a different thickness. When the torch reaches the point of change, a limit switch on the boom gives a signal which shifts control to the second station.

All these refinements contribute toward a practical welding solution to the problem of quality welding various complex shapes such as air intake ducts for aircraft.

For details, circle No. 102 on Reader Information Card.

Portable Welding Curtains

Portable welding curtains for safety and to help maintain the gas shield in gas-shielded arc welding under drafty conditions are announced by National Cylinder Gas Division of Chemetron Corp.

The screens are available in 4-panel models, providing complete enclosure on four sides, and in triple- and single-curtain models, in a variety of sizes ranging up to 8 ft high and 8 ft wide.

Frames are constructed of 1-in. tubular steel with a rust-proof black oxide finish. Curtains are held in place by lacing through metal grommets, and are available in 12-oz olive drab fire-resistant duck, yellow neoprene-coated fiberglas and aluminized asbestos cloth.

For details, circle No. 103 on Reader Information Card.

Attention—Authors!
See pages 509–510

For details, circle No. 31 on Reader Information Card →

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ELECTRODES

No matter what the job, there's a Sureweld Electrode to do it better. Want slow burn off rate to fast bead deposition rate with maximum penetration? Want slow and cool deposition with minimum penetration? Want special alloying or shielding characteristics? Whatever you want, you can get it in Sureweld Electrodes.

NEW . . . Sureweld Electrode Data Sheets. Complete and detailed information on each electrode . . . welding characteristics, welding procedures, color identifications, physical properties of deposited metal, recommended current ranges per stock sizes, etc. Just write today outlining the applications in which you are interested and we will be happy to forward data sheets to meet your needs. There is no obligation.

NEW . . . A completely re-designed package. All Sureweld Electrodes are now packaged in this handsome, strong, moisture-resistant carton providing maximum protection. In addition, for your convenience, easy access has been provided. With a simple pull of the "Zipper", about one-third of the carton comes away, and the electrodes are instantly available for use. Automatically you have a temporary storage facility that can be moved easily from job to job.

SUREWELD 6014 ELECTRODE:

An all position electrode for mild steel, it operates equally well on AC or DC. Approximately one-sixth of the deposited metal comes from the coating of this electrode, a thick coating with a substantial percentage of iron powder. The balance of the metal deposited comes from the core wire. In addition, the heavier coating has substantial heat capacity which permits higher current rates without damage to the coating. The result is an increase of 20% to 40% in deposition rate.

The "drag technique" may be used with Sureweld 6014 electrodes, with the tip held in contact with the plate, or with a free arc. These electrodes have found wide use for welding construction equipment, sheet metal, farm implements, foundry equipment, pressure vessels, pipe and fittings, etc.

This is only some of the information contained on the Sureweld 6014 Electrode Data Sheet . . . get this and others by writing or calling your nearby NCG office today.

NCG®

NATIONAL CYLINDER GAS

DIVISION OF
CHEMETRON CORPORATION CHEMETRON

840 N. Michigan Ave., Dept. E-IE, Chicago 11, Illinois

NCG sales offices and authorized dealers are located in all principal cities. Consult the yellow pages for the office nearest you.

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FOR WORK IN A CONTROLLED ATMOSPHERE

BLICKMAN
VACUUM DRY BOX

Designs and specifications are available for a variety of welding enclosures for research and production welding, and for work in the fields of metallurgy and physical chemistry. These enclosures can be fully evacuated and then be filled with an inert gas for welding in an inert atmosphere. Write for Technical Bulletins on various types of welding enclosures: S. Blickman, Inc., 3905 Gregory Avenue, Weehawken, N. J.

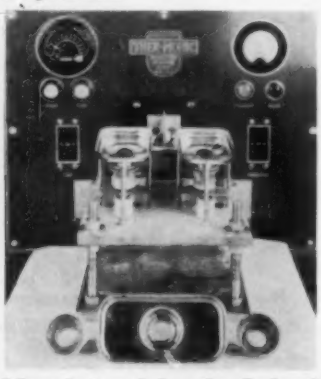
BLICKMAN
LABORATORY EQUIPMENT

Look for this symbol of quality Blickman-Built

For details, circle No. 33 on Reader Information Card

High-speed Soldering

Soldered joints in containers for perishable foods are produced by a Ther-Monic unit with a specially designed fixture. A solder ring controls the exact amount of solder used and the application of induction heat provides the proper control of the operation.



Manufactured by the Induction Heating Corp. of 181 Wythe Ave., Brooklyn 11, N. Y., the machine is said to produce 240 units per hr and consists of a $1^1/_2$-kw generator and a two-place coil attached to a single fixture for ease of mounting and storing.

For details, circle No. 114 on Reader Information Card.

CO_2 Welding Gun

A manual Aircomatic (Air Reduction's gas-shielded metal-arc process) welding gun for use on mild steel using carbon dioxide (CO_2) as a shielding gas has been placed on the market by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y.

The air-cooled gun, designated Model AH60-B, has a continuous duty rating of 600-amp dc when using "buried arc" CO_2 techniques. It is said to accommodate hard welding wires ranging from 0.035-in. through $^3/_{32}$ in. fed from conventional Airco wire feeders.

For details, circle No. 104 on Reader Information Card.

Magnetic-flux Cleaner

The Lincoln Electric Co., Cleveland 17, Ohio, offers the Magnetic Separator, which is said to improve performance and weld quality by removing from submerged-arc welding flux contaminating materials accidentally picked up in handling or use.

The separator, a funnel used to fill the flux container of the automatic welding machine, contains three cylindrical alnico magnets. Mill scale, pieces of steel, grindings, spatter and foreign material that were picked up during the previous use of the flux are removed from the flux as it passes across the three magnets.

The magnetic separator is designed for use with mild-steel and low-alloy-steel fluxes.

For details, circle No. 105 on Reader Information Card.

Flux-removing Compound

Bernite 45 is said to quickly and effectively dissolve flux residues as a result of brazing or soldering. It is intended for those joints that have cooled leaving a tenacious glass-like residue. According to Bernard Chemical Products Co., 98–21 Linden Blvd., Ozone Park 17, N. Y., it will

To Prospective Authors for 42nd Annual Meeting!

All authors interested in presenting papers at the AWS 42nd Annual Meeting to be held in New York City on April 17–21, 1961 are advised of a change in preliminary arrangements.

The usual forms, "An Invitation to Authors" and "Authors Application Form" have been printed as a detachable insert on pages 509-510 of this issue of the Welding Journal instead of being sent through the mails.

ATOM/ARC

THE MOST IMITATED ELECTRODE IN AMERICA

In October, 1954, Alloy Rods Company "scooped" the welding electrode industry. For the first time an all position—iron powder—low hydrogen electrode was made available to the American welding industry. Immediate acceptance by the nation's most prominent and discerning fabricators proved Atom•Arc to be the most outstanding new electrode development on the American market and for nearly one and one-half years Atom•Arc was in the enviable position of being the only electrode of this type available. Due to consistent high quality, Atom•Arc has remained the leader in its field and because of this leadership, is the most imitated electrode in America.

Alloy Rods Company is truly the leader in the alloy welding industry, and we suggest that you consult us regarding iron powder low hydrogen electrodes ranging in tensile properties from 70,000 p.s.i. to 120,000 p.s.i. and Charpy impact values from 240 ft. lbs. at room temperature to 15 ft. lbs. at —150° F. Specify your requirements from the following:

ATOM•ARC 7018 AWS Class E7018	**ATOM•ARC 8018N** AWS Class E8018-C2	**ATOM•ARC 8018CM** AWS Class E8018-B2	**ATOM•ARC 10018MM** AWS Class E10018-D2	**ATOM•ARC 502** AWS Class E502
ATOM•ARC 7018Mo AWS Class E7018-A1	**ATOM•ARC 8018** AWS Class E8018-C3	**ATOM•ARC 9018CM** AWS Class E9018-B3	**ATOM•ARC 12018NMV** AWS Class E12018-G	**ATOM•ARC 'T'** For Welding T1 steel AWS Class E11018-G

ALLOY RODS COMPANY

YORK, PENNSYLVANIA

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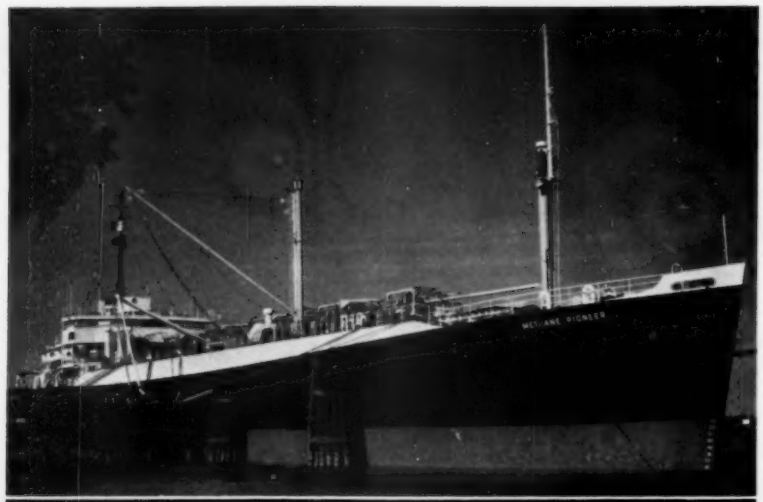
TWENTY YEARS OF LEADERSHIP IN THE DEVELOPMENT OF QUALITY ALLOY ARC WELDING ELECTRODES

For details, circle No. 34 on Reader Information Card



Job report courtesy of
Conch Methane Co., Ltd.

when pipe joints must be completely dependable at minus 258°F

The engineers who successfully "broke through" the problem of handling liquefied methane gas on and off the "METHANE PIONEER" at minus 258°F had to "play it safe" in every respect. To provide unquestionably *safe* stainless pipe joints, Arcos EB Consumable Weld Inserts were used to make the important root passes.

EB Inserts permit welding to be done from one side only. They eliminate back-up ring obstruction and produce a smooth inside contour to expedite gas flow. If you are not familiar with the advantages of EB Weld Insert for "tough" pipe joining problems, write ARCOS.

*Trademark of General Dynamics Corp.

WELD WITH ARCOS

EB* WELD INSERT

ARCOS CORPORATION, 1500 South 50th Street, Philadelphia 43, Pa.

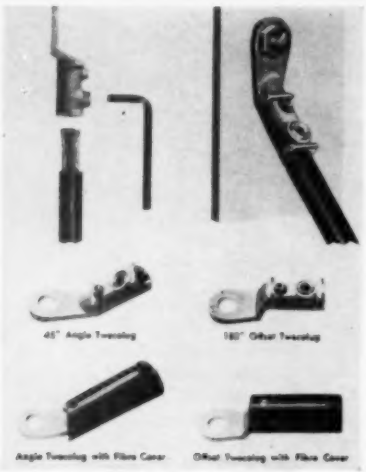
For details, circle No. 35 on Reader Information Card

dissolve these residues in a matter of minutes and pickle the metal as well.

For details circle No. 106 on Reader Information Card.

Efficient Cable Connectors

A ball-point type mechanical lug that can be quickly and easily attached to stranded welding cable has been announced by Tweco Products, Inc., Box 666, Wichita, Kansas. Made of high-conductivity copper, the lug barrel is tapped to accept a cadmium-plated steel-ball-point screw.



The design of the lug is said to assure that every strand of the cable will be under pressure and carry its share of the electric load.

The Tweco Ball-point Type Lugs come in two sizes to handle from No. 4 through 4/0 Cable. They are available with or without the fiber insulating cover.

For details, circle No. 107 on Reader Information Card.

Safety Shields

Safety shields for on-the-job protection during welding and grinding operations and for use as machine curtains or partitions, where safety and protection are required, are supplied by National Cylinder Gas Division of Chemetron Corp.

The shields are available in four sizes ranging from 18 to 36 in. in height and from 42 to 72 in. in overall length. Construction is of tubular steel with a black-oxide finish. Connecting rods are inserted into the open ends of uprights to form the frame and the curtains are fastened to the frame with heavy snap fasteners. The curtains are of heavy olive drab duck with flame-resistant finish, water- and mildew-resistant.

For details, circle No. 108 on Reader Information Card.

Packaged Torch Equipment

All Dockson welding and cutting outfits will now be packaged in colorful, specially designed shipping-display cartons, according to a recent

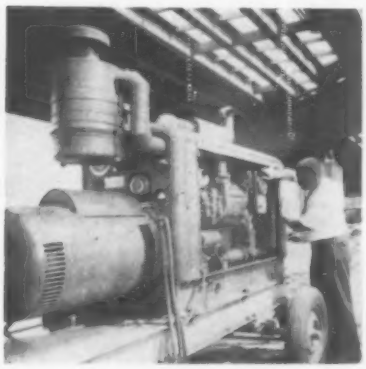
announcement by Dockson Corp., Detroit, Mich.

The new packaging doubles as a sturdy shipping container of corrugated stock and as an eye-catching, point-of-sale aid for the distributor.

For details, circle No. 109 on Reader Information Card.

Stud-welding Equipment

A diesel-driven d-c welding generator, designed for field installation of $^{7}/_{8}$-in. diam shear-connector and



other type studs, is announced by the Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

Three heavy-duty NS 9 stud welding guns may be operated simultaneously from this source, designated the Nelwelder FD Unit, which furnishes power at 2000 amp, 80 v. With accessory controls, the machine may be used for arc-air gouging or hand-arc welding, according to the manufacturer.

For details, circle No. 110 on Reader Information Card.

Job Report Courtesy of
Leader Iron Works, Inc., Decatur, Ill.

When stainless welds must also resist heat and pressure

This sturdy autoclave made of Type 316 stainless steel must operate under pressures up to 1000 psi at 600°F. Code specifications called for X-ray quality weld. To meet all these conditions for successful and long performance Arcos Chromend KMo (Type 316) electrodes were used for joint fabrication. When you use Arcos Stainless Electrodes you can always count on their providing multiple benefits.

WELD WITH ARCOS

STAINLESS ELECTRODES

for quality weld metal

ARCOS CORPORATION • 1500 South 50th St., Philadelphia 43, Pa.

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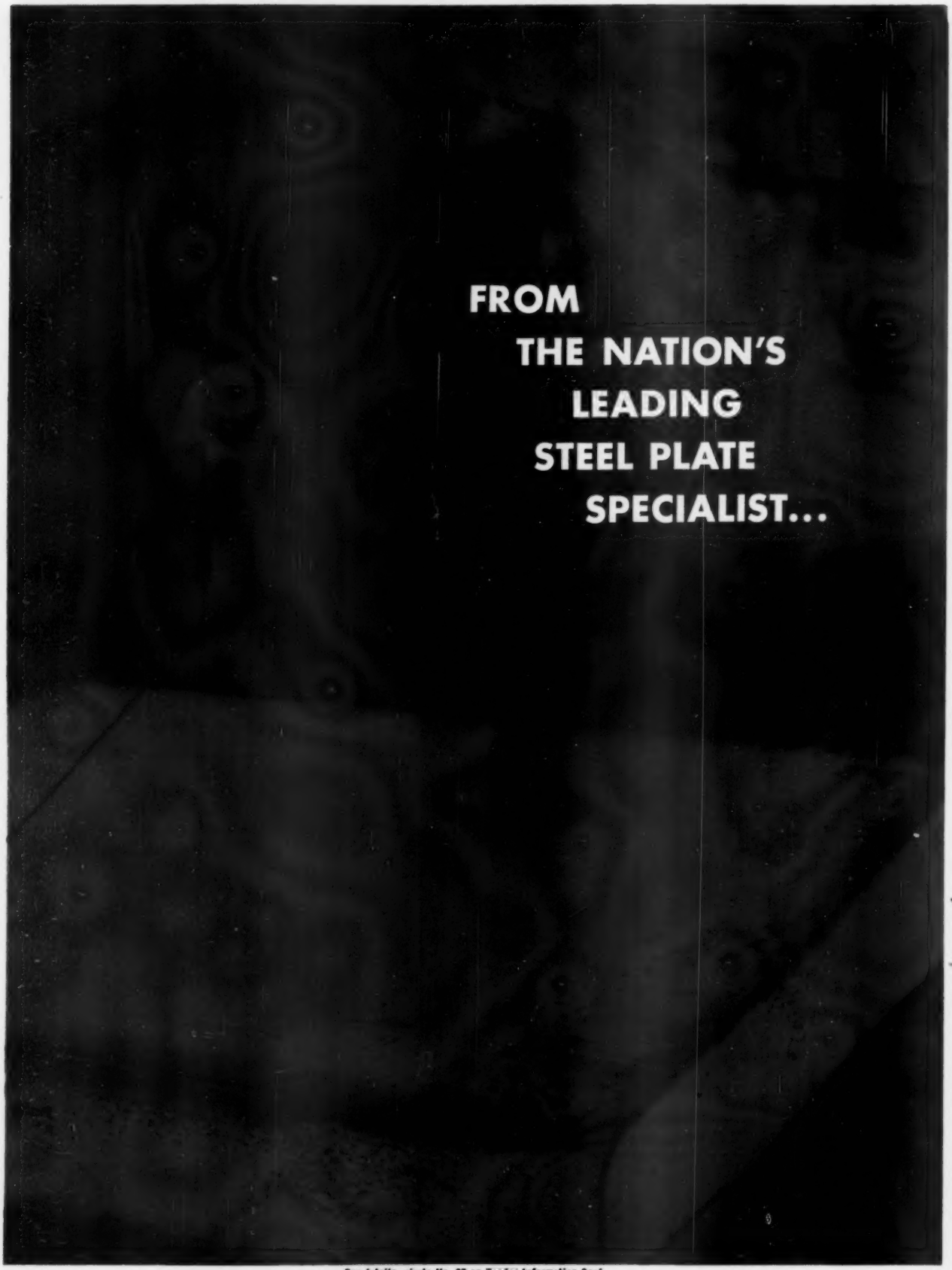


For details, circle No. 37 on Reader Information Card

LUKENS PLATE-MATE welding electrodes and wire

matched to Lukens Steel Company's broad line of carbon, alloy and clad steel plates and heads.

From a steel plate producer . . . a single source of materials supply for the steel plate fabricator.

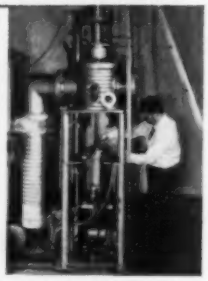
Write for the Lukens Plate-Mate Technical Catalog. Dept. Q50, Service Building, Lukens Steel Company, Coatesville, Pa.

LUKENS PLATE MATE

For details, circle No. 37 on Reader Information Card

NEWS
from the NRC Vacuum MICRONICLE*

PURER METALS WITH ELECTRON BEAM



Hard to melt materials such as tungsten, tantalum, zirconium, molybdenum, columbium and other high performance metals can now be melted without contamination. Electron beam technique can be used for either melting or contamination-free welding.

These furnaces can operate at highest vacuums attainable in a furnace and melt stock in any form. Melting temperature is almost unlimited. Heating can be concentrated or spread out as desired.

*FREE. Contains news about improving products with NRC High Vacuum Equipment. Write on firm letterhead. Dept. J-3, 160 Charlemont St., Newton 61, Massachusetts.

NRC EQUIPMENT CORPORATION

For details, circle No. 38 on Reader Information Card

When You Weld Cast Iron Select the Correct
Fuse-Well
CAST IRON WELDING RODS OR ELECTRODES

FUSE-WELL NO. 11

FUSE-WELL No. 11, *Square*—Gray Cast Iron Welding Rod for Acetylene use in filling or building up new or worn castings producing machineable welds.

FUSE-WELL NO. 12

FUSE-WELL No. 12, *Round*—Has the same uses and analytical ingredients as Fuse-Well No. 11.

FUSE-WELL NO. 14 MOLY

FUSE-WELL No. 14, *Moly*—An Iron Base Rod with alloys added for finer grain structure and greater strength.

FUSE-WELL NO. 22

FUSE-WELL No. 22, *Electrode* — Light coated Rod to be used for AC or DC welding in the fabricating and repairing of cast iron castings.

THE CHICAGO HARDWARE FOUNDRY CO.
Weld Rod Division
NORTH CHICAGO, ILLINOIS

For details, circle No. 40 on Reader Information Card

400-psi Regulator

A large capacity, diaphragm-type pressure regulator has just been announced by The Bastian-Blessing Co., 4201 W. Peterson Ave., Chicago 46, Ill. The RegO 1680 Series

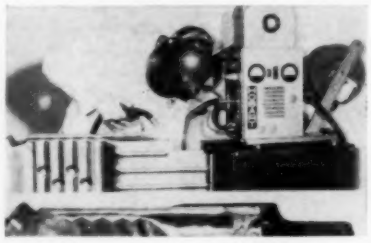
regulator may be used with most noncorrosive gases and is particularly useful in controlling the flow of oxygen, nitrogen and other gases which originate at a liquid container at a maximum inlet pressure of 400 psi.

For details, circle No. 111 on Reader Information Card.

Micro-wire Welding Process

Micro-wire welding is an automatic welding process developed by Hobart Bros. Co., Troy, Ohio, for carbon-dioxide-shielded arc welding of mild steel from 24 gage to $^1/_4$-in. thickness.

The process was named for the 0.020 to 0.045-in. diam welding wire



(about the size of a pin or paper clip) that is fed continuously from a spool. Equipment includes a lightweight gun-cable assembly, a wire-feed unit, gas supply and regulation apparatus, and a power source of the constant voltage or variable slope type.

The gun is kept cool by atmospheric air. All wire-feeding facilities, gas tubes and wires are contained inside one extruded cable jacket which measures only $^3/_4$ in. in diam.

For details, circle No. 112 on Reader Information Card.

BATEMAN BANTAM IRON WORKER
THE ONLY IRON WORKER OF ITS KIND ON THE MARKET TODAY

No Grinding Necessary After Cut. One Stroke Cycle Clutch Operated by Hand or Foot.

The Bateman "Bantam" cuts 2" x 2" x ¼" angles and ¼" x 4" flats. Standard punches will fit this machine. The Coper will cope 1¼" through ⅛" material. It will punch ½" hole through ¼" material. With the clutch open, the Bantam will make 44 strokes per minute. It is made of high-grade cast iron, with the clutch, pin and dog made of hardened steel. The blades are made with tool steel. It is powered with a fly wheel and gear drive, and uses a small ¾ hp motor, 1750 rpm.

Bateman Bantam with punch ... $575.00
Shear only ... $495.00
Shipping wt. 750 lbs.

BATEMAN FOUNDRY & MACHINE
MINERAL WELLS, TEXAS

For details, circle No. 39 on Reader Information Card

High-frequency Stabilizer

A high-frequency stabilizer for inert-gas arc welding has been announced by Metal & Thermit Corp. Rahway, N. J. It is designed for use with standard a-c or d-c welding machines to convert it for inert-gas-shielded arc welding on aluminum, stainless and alloy steels, copper, magnesium and dissimilar metals. It operates from a 230-v source and

has a 0- to 600-amp capacity. Controls include a gas valve, high-frequency selector, gas afterflow, remote control cable and switch.

For details, circle No. 113 on Reader Information Card.

For details, circle No. 44 on Reader Information Card >

Move up to
Airco Quality

Industry's Top Line
Welding and Cutting Torches, Tips and Regulators

BACKED BY THE MOST EXPERIENCE . . . AIR REDUCTION

AIRCO QUALITY

Quality in Design
Quality in Manufacture
Quality in Service

Quality starts with raw materials—this gleaming stock of copper and brass is used in the manufacture of Airco welding and cutting torches, tips and regulators.

The royal blue flames of automatic gas brazing make strong, smooth, uniform joints in Airco torches. This machine brazes parts in brass, bronze, copper and stainless steel.

A test of quality, in capable hands: every torch must prove its capacity, gas tightness and proper operation before it can bear the AIRCO trademark.

Costly special machines flawlessly drill tip orifices 0.025" in diameter—one more quality step in manufacturing Airco Cutting Torch Tips.

Tips must test out at top quality, also—every one is tested separately for accuracy of hole alignment and stability of gas flow.

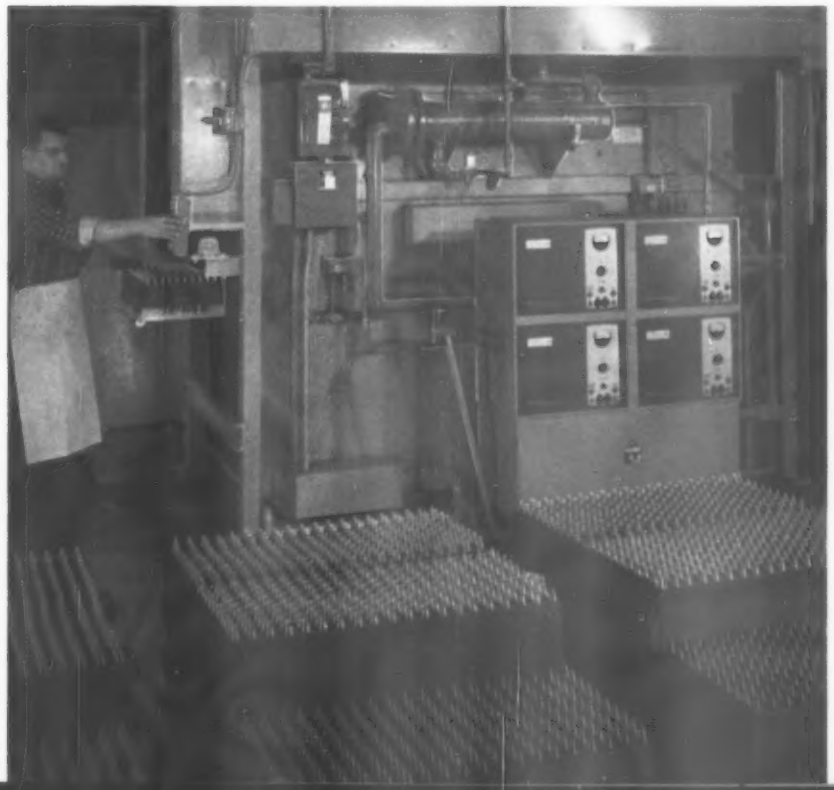
Whatever your welding and cutting needs—whether they call for high **precision** or high **production,** or both—you'll get the finest results with quality Airco torches, tips and regulators. These photographs, taken at the Air Reduction Equipment Manufacturing Plant, Union, N. J., help give a small idea of how quality is the keynote from start to finish in every product that's marked AIRCO.

SEE YOUR AUTHORIZED AUTHORIZED AIRCO DISTRIBUTOR DISTRIBUTOR

Precision means quality. This multi-spindle machine drills and taps precisely-angled holes in Airco product components.

A distinctive sheen proves quality, too. Airco takes great pains to produce top appearance as well as reliable operation in Airco Regulators.

Testing for gas tightness and accurate gas control— industry's highest testing standards mean Airco Regulators can be relied on for accuracy and durability.



Welding and cutting tips are ultrasonically stripped of burrs, chips and oils accumulated during the manufacturing process.

Photographs: Robert Yarnall Richie

AIRCO QUALITY

...backed by the most experience

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When you buy Airco products, you've bought the finest that modern manufacturing techniques can produce. But there's more than that to **Airco quality.**

Airco Products are backed by a nationwide network of sales offices and Authorized Distributors. This country-wide staff of experts is willing and eager to help you with your own special problems.

AIRCO QUALITY—AS NEAR AS YOUR PHONE

You'll find an Air Reduction Sales Office, or an Authorized Airco Distributor in your classified telephone directory, listed under "Welding Equipment and Supplies." Use these outlets as your source, not only of welding and cutting torches, tips and regulators—but also for electrodes, arc welding machines, gas-shielded arc welding equipment, supplies and accessories and all industrial gases. For any welding or cutting need—call Airco.

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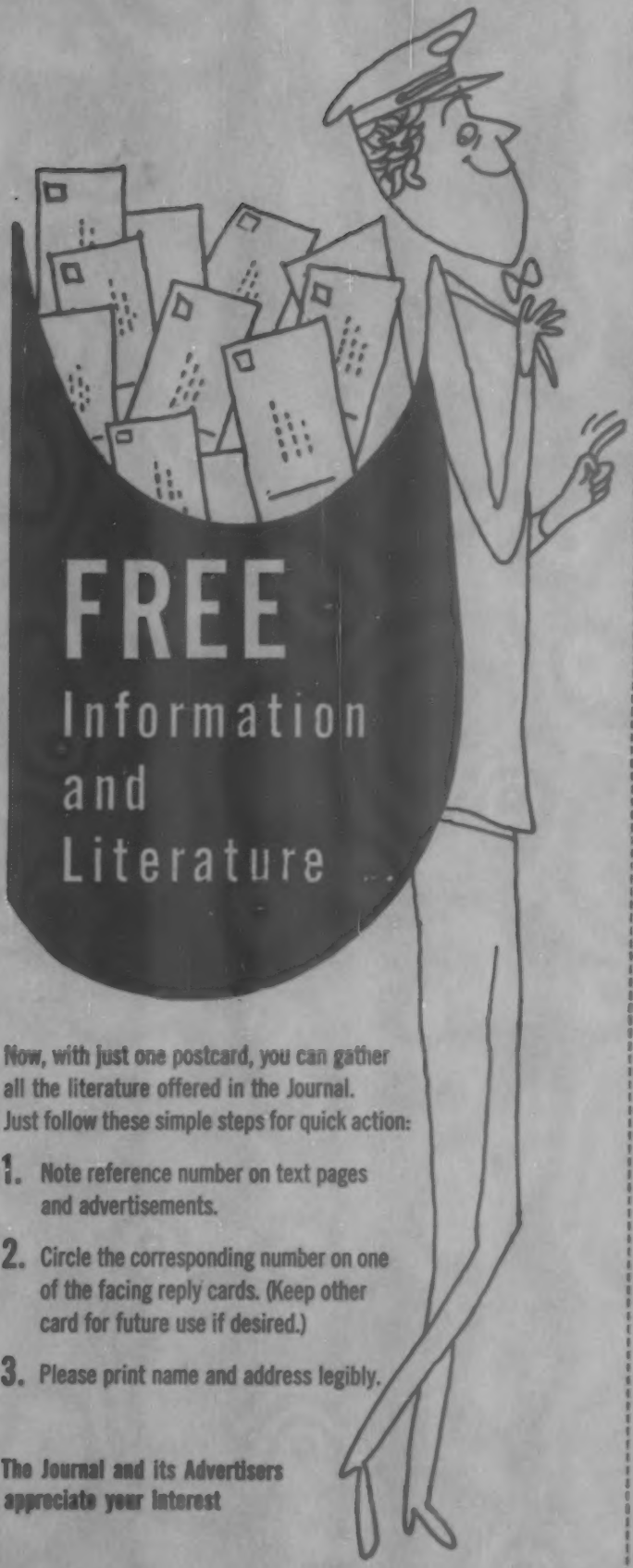

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7	32	57	82	107	132
8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
23	48	73	98	123	148
24	49	74	99	124	149
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6	31	56	81	106	131
7	32	57	82	107	132
8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
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Index to ADVERTISERS

PAGE	
523	Acro Welder Mfg. Co.
559–562 Outside Back Cover	Air Reduction Sales Co.
553	Alloy Rods Company
517	All-State Welding Alloys Co., Inc.
521	Aluminum Company of America
467	American Platinum & Silver Division, Engelhard Industries, Inc.
532	The Arcair Company
554, 555	Arcos Corporation
538	Automation Industries, Inc.
534	Bastian-Blessing Company
558	Bateman Foundry & Machine
552	S. Blickman, Inc.
558	Chicago Hardware Foundry Co.
537	Eastman Kodak Company
524, 525	General Electric Co., Electronic Components Div.
539	General Electric Co.
469	Handy & Harman
543	Harnischfeger Corp.
463	Hobart Brothers Co.
545	Instrument Control Co.
470	International Nickel Co., Inc.
Inside Front Cover	Jackson Products
513	Lenco, Inc.
546, 547	Linde Company, Division of Union Carbide Corporation
556, 557	Lukens Steel Company
514	Maitlen and Benson, Inc.
538	Merrill Brothers
529, 531, 533, 535	Metal & Thermit Corporation
472	Miller Electric Mfg. Co.
515	National Carbide Company
551	National Cylinder Gas, Division of Chemetron Corporation
541	National Welding Equipment Co.
558	NRC Equipment Corp.
465	Picker X-Ray Corporation
539	A. O. Smith Corporation
549	Tempil® Corporation
530	Thomson Electric Welder Co.
546, 547	Union Carbide Corporation Linde Company
Inside Back Cover	Victor Equipment Co.
527	Wall Colmonoy Corp.

Welding Research

Sponsored by the Welding Research Council of the Engineering Foundation

WRC

SUPPLEMENT TO THE WELDING JOURNAL, MAY 1960

1959 ADAMS LECTURE

The Science of Arc Welding

Evaluation of the present knowledge provides the engineer and the research man with basic concepts of volt-ampere relationship, distribution of field intensities and temperatures, metal transfer, spatter, arc forces and motion, melting rate, weld area, melting ratio and other related factors

BY CLARENCE E. JACKSON

Part II*—Consumable-electrode Welding Arc

The discussion up to this point has had to do with a welding arc using a tungsten electrode with an inert-gas mantle. This is the least complicated of the welding arcs and lends itself readily to the investigation which has been reported. It is hoped that some of these approaches can be used in further studies of the consumable-electrode welding arc. Many useful fundamental data for the consumable-electrode inert-gas welding process are still not available. In the case of the covered electrode or submerged-arc welding process, further complications exist since the electrical and thermal properties are affected by highly excited metallic and fluxing components and the direct methods used for inert-gas processes may be difficult to apply.

Melting Rate of Consumable Electrode

The effects of welding variables on electrode melting characteristics in arc welding with consumable electrodes have been the subject of widespread investigation, and much information appears in the literature.[21-24] Much of this information was obtained for the purpose of observing the effects of welding variables on the appearance, quality, composition and the mechanical properties of the deposit rather than on their specific effects on the melting rate of the electrode. Only recently has the effect of self-preheat on melting rate been studied.[25, 26] In many investigations it has been pointed out that, in general, the melting rate of the electrode increases with current (Fig. 25). Tandem electrodes coupled to a three-phase power supply show a similar behavior. It can be shown that the I^2R heating in a steel-electrode extension is related through fundamental electrical laws to the current density and electrode extension (Fig. 26).

The arc melting rate of the electrode is determined by the anode or cathode heating at the electrode depending upon the polarity used. Lesnewich has shown that anode heating increases with electrode diameter and welding current for gas-shielded welding processes. Wilson *et al.*, have shown that with both a-c and d-c reverse polarity, the arc melting rate increases with an increase in

CLARENCE E. JACKSON is Associate Manager, Electric Welding Department, at the Development Laboratory, Linde Co., Division of Union Carbide Corp., Newark, N. J.

* Part I—"Definition of Arc" appeared on pages 129-s–140-s of April 1960 issue of the WELDING JOURNAL Research Supplement.

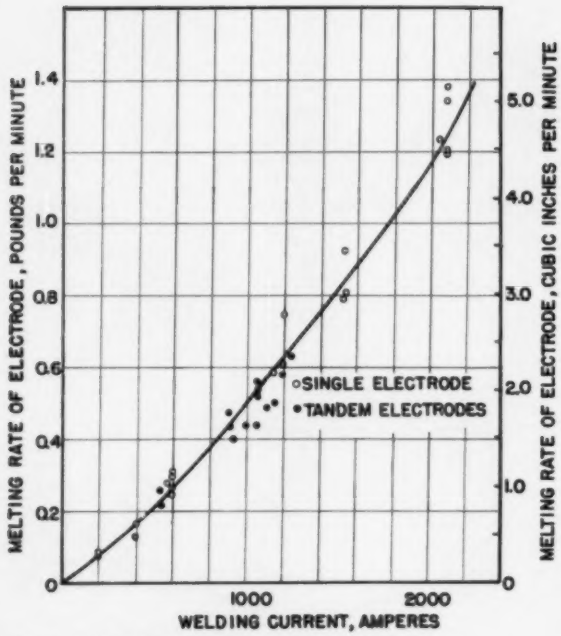
MELTING RATE OF ELECTRODE, POUNDS PER MINUTE
MELTING RATE OF ELECTRODE, CUBIC INCHES PER MINUTE
WELDING CURRENT, AMPERES
SINGLE ELECTRODE
TANDEM ELECTRODES

Fig. 25—Effect of welding current on melting rate of electrode using the submerged-arc process

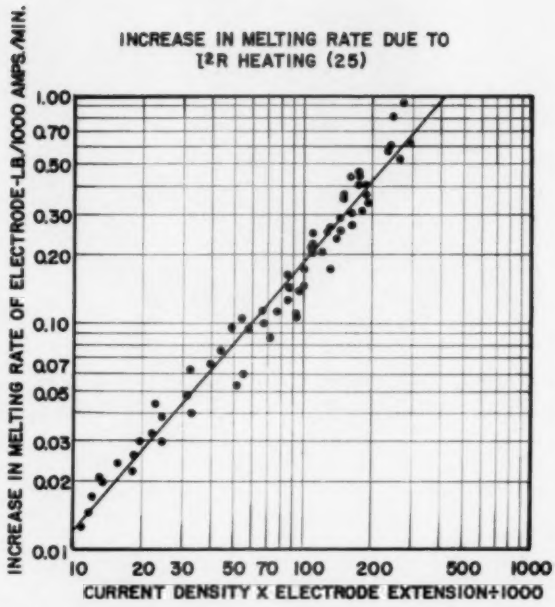
INCREASE IN MELTING RATE DUE TO I²R HEATING (25)
INCREASE IN MELTING RATE OF ELECTRODE-LB/1000 AMPS/MIN.
CURRENT DENSITY X ELECTRODE EXTENSION÷1000

Fig. 26—Increase in melting rate due to I^2R heating[25]

electrode diameter and current. Lesnewich has further indicated that cathode heating is similar to anode heating in that it is dependent upon current and electrode diameter.

Further data have been reported by Wilson and Claussen[27] on the effect of electrode extension, polarity, voltage, current and electrode diameter, on the electrode melting rate using steel, copper and nickel electrodes with the gas-shielded and submerged-arc processes. Further, the melting rate was measured for $^1/_{16}$-in. diam electrodes for steel, copper, nickel, cobalt, aluminum, molybdenum and titanium for electrode negative in argon at 200 to 260 amp (Fig. 27).

Melting rates of a $^1/_{16}$-in. diam carbon-steel electrode with $^1/_2$ in. extension were measured by Wilson and Claussen[27] using various gases for protection. Direct current was used for all tests with both positive and negative electrode polarity. For comparison, tests were carried out in air with no shielding gas. The results of these tests are shown in Table 4. The melting rates for all shielding gases were higher with direct-current straight polarity (electrode negative) than with reverse polarity (electrode positive). The differences in melting rates with the various shielding gases were comparatively small with the exception of oxygen with electrode positive which produced a melting rate well above those of the other gases.

The experimental results show that a number of factors influence melting rate for any metal. The level of current and polarity are the most outstanding and, probably, the most significant factors. In using the data, it was found that the arc melting rate in pounds per thousand amperes varies considerably as the current and current density are increased (Fig. 28). At very low currents, the melting rate is zero and the only loss of metal from the electrode is by vaporization. When the current reaches the value at which conduction through and radiation from the electrode are inadequate to preserve heat balance, metal drops form and are transmitted across the weld zone by the welding action. The effect of voltage does not appear to be consistent. With decreasing voltage, the melting rate increases faster with reverse polarity than for straight polarity. The decrease in melting rate with an increase in voltage is typical of the data reported which often indicates that increased energy does not necessarily result in increased melting rate. Current, not voltage or

Table 4—Effect of Different Shielding Gases on the Melting Rate of $^1/_{16}$-in. Carbon-steel Electrode

Shielding gas	Flow of gas, cfh	Amperes	Volts	Ipm	Polarity	Electrode melting rate, lb/min/1000 amp
Argon	40	250	25	10	DCR	0.49
Argon	40	240	31	10	DCS	0.86
Argon + 5% O_2	40	245	24	10	DCR	0.46
Argon + 5% O_2	40	245	22	10	DCS	0.78
Helium	120	250	30	10	DCR	0.59
Helium	120	250	30	10	DCS	0.92
CO_2	40	250	30	10	DCR	0.52
CO_2	40	250	30	10	DCS	0.85
Oxygen*	40	250	30	10	DCR	0.72
Oxygen*	40	250	30	10	DCS	0.79
Nitrogen*	40	250	30	10	DCR	0.61
Nitrogen*	40	255	30	10	DCS	0.82
Air*	40	240	30	10	DCR	0.58
Air*	40	265	30	10	DCS	0.91

* Weld deposit unsatisfactory.

energy, appears to be the governing factor.

Hummitzsch[28] has shown a trend between the melting rate (lb/min) for covered electrodes and ionization potential of the covering. The melting rate of electrodes for Hummitzsch's results given in Fig. 29 using about 140 amp appeared to be related to the heats required for formation of the compounds used in the covering added to the heat for vaporization and ionization.[29] In these tests, the melting rate is lowest with cesium and barium compounds and is increased with magnesium, titanium and silicious compounds. Khrenov[30] has suggested that the temperature (° K) of the welding arc is equal to 800 V_i where V_i is the average effective ionization potential. Semenova[31] with a similar approach gives the temperature as 660 V_i.

Temperature of Weld Metal

Measurements of globular temperature from steel electrodes by Erokhin[32] indicated 2000 to 2400° C as a temperature, but most investigators have not shown as high a temperature for the globule. It is not expected that a temperature much higher than the melting point exists at the time the globule leaves the electrode. A calorimetric determination indicated that the temperature of mild steel in the submerged-arc welding puddle was 1770° C. Christensen and Chipman[33] have indicated a maximum temperature of slightly less than 2000° C for measurements of the weld-metal crater based on metallurgical reactions.

Volt-ampere Characteristics

The volt-ampere characteristics for the consumable-electrode arc-welding processes have not received the rigorous attention which has been given to the nonconsumable tungsten-electrode process. Results reported by Herbst and McElrath[34] indicate that for the consumable-electrode inert-gas process, as the welding current is decreased toward 150 amp for steel electrodes with argon, argon plus 5% oxygen and helium, the arc potential decreased to a possible minimum (Fig. 30). The data do not confirm a rise at the lower currents similar to that shown by many investigators for the tungsten-arc process.

No indication of a rise in potential is shown by Verchenko[35] in a discussion of static arc characteristics of gas-shielded welding with consumable aluminum electrodes. Since Verchenko shows (Figs. 31, 32 and 33) a linear relation of the volt-ampere characteristic and

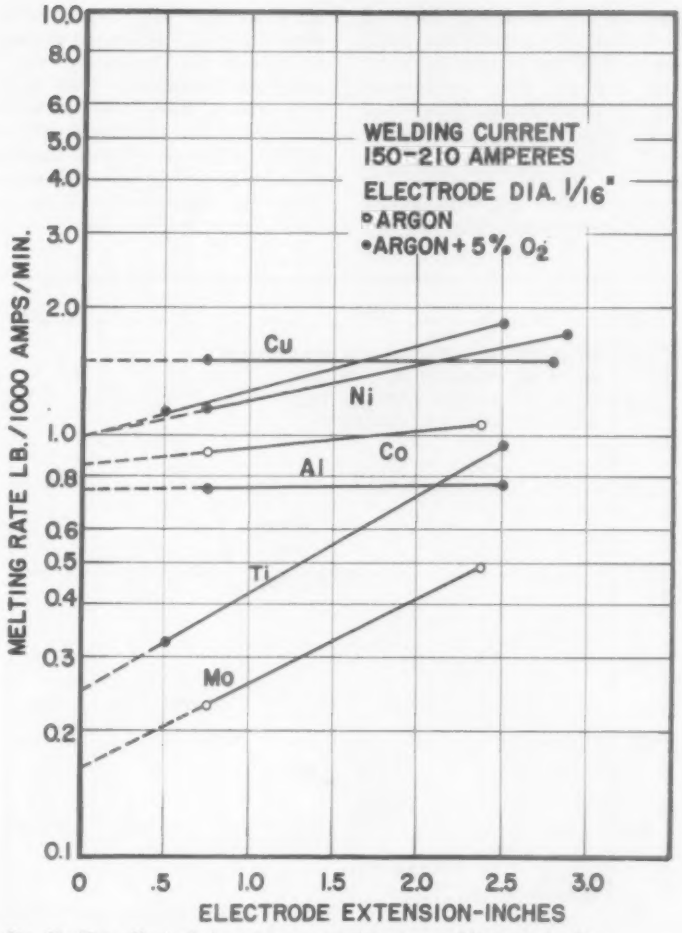

Fig. 27—The effect of electrode composition on melting rate in the inert-gas consumable-electrode process[27]

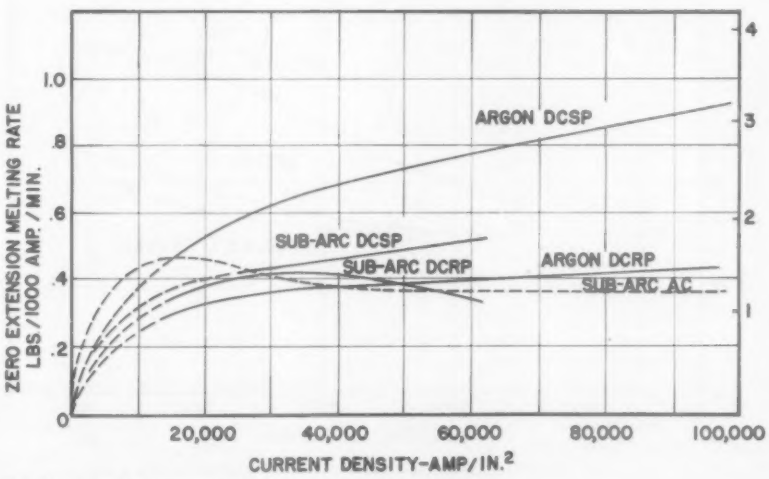

Fig. 28—Effect of current density on zero melting rate

extrapolates the extensive data to zero current, it is probable that the tests gave no indication of a rise in voltage with decreasing current. Additional tests with lower currents with $^1/_{16}$-in. or smaller diameter electrodes are suggested. Further, no reversal in slope has been shown in the voltage-arc length characteristics (Fig. 34) for an aluminum electrode (0.059 in. diam) in either argon or helium by either the American[36] or Russian[35] investigators. The relationship shown may not describe the conditions for all consumable-electrode processes. Some additional data for submerged-arc and covered-electrode processes will be given later.

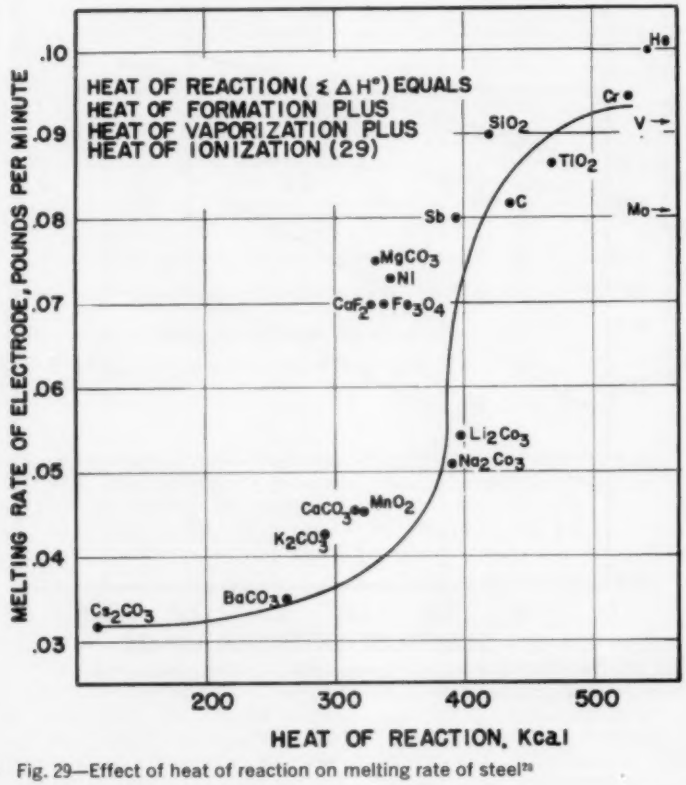

Fig. 29—Effect of heat of reaction on melting rate of steel[29]

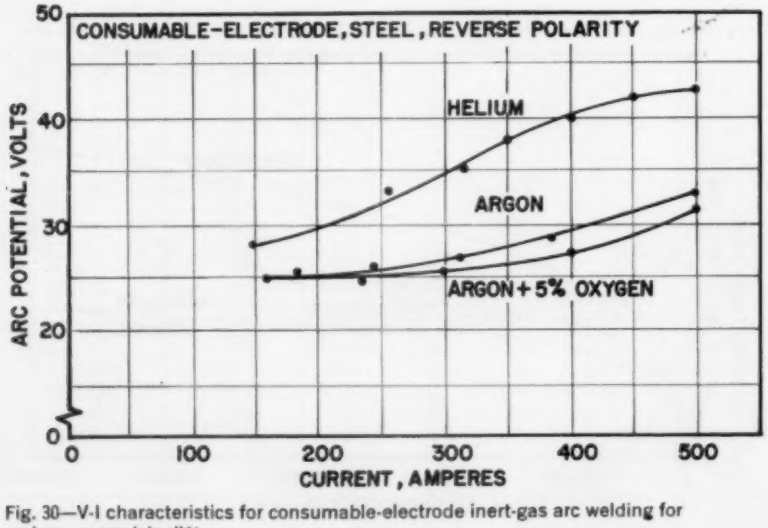

Fig. 30—V-I characteristics for consumable-electrode inert-gas arc welding for various gases (steel)[34]

Transfer of Metal

A quantitative analysis of metal transfer in the consumable-electrode inert-gas process, has in many of the other fundamental studies been hampered, heretofore, by the lack of sufficient experimental data. Considerable additional data are now available to the researcher in which metal transfer from the

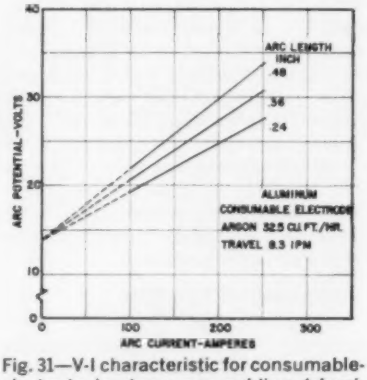

Fig. 31—V-I characteristic for consumable-electrode inert-gas arc welding (aluminum 0.059-in. diam)[35]

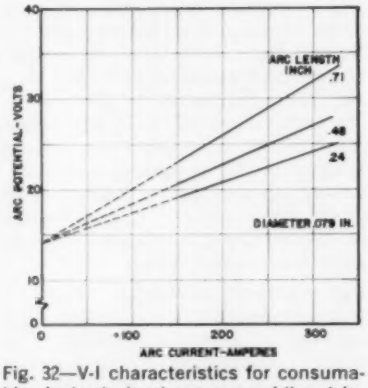

Fig. 32—V-I characteristics for consumable-electrode inert-gas arc welding (aluminum 0.079-in. diam)[35]

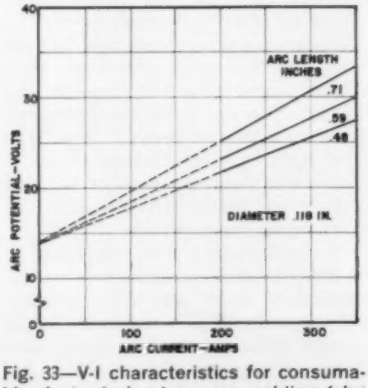

Fig. 33—V-I characteristics for consumable-electrode inert-gas arc welding (aluminum 0.118-in. diam)[35]

electrode to the weld puddle was observed using high-speed photographic techniques. As is generally agreed, metal transfers from the electrode to the weld puddle chiefly by means of drops of metal varying in diameter up to approximately 0.2 in. Several forces act upon the droplet, some hindering and some promoting transfer. It is the balance of these forces that is important. The next section will consider the actual mechanics of metal transfer in the consumable-electrode gas-shielded welding process. The discussion is based on empirical facts and data from which theoretical relations can be introduced. The films which were used for study of the welding zone, were taken by means of a high-speed camera at the rate of 3000 to 7000 frames per second. The series used both color and black and white films, and studied welding with different shielding gases, currents, welding electrodes, volt-

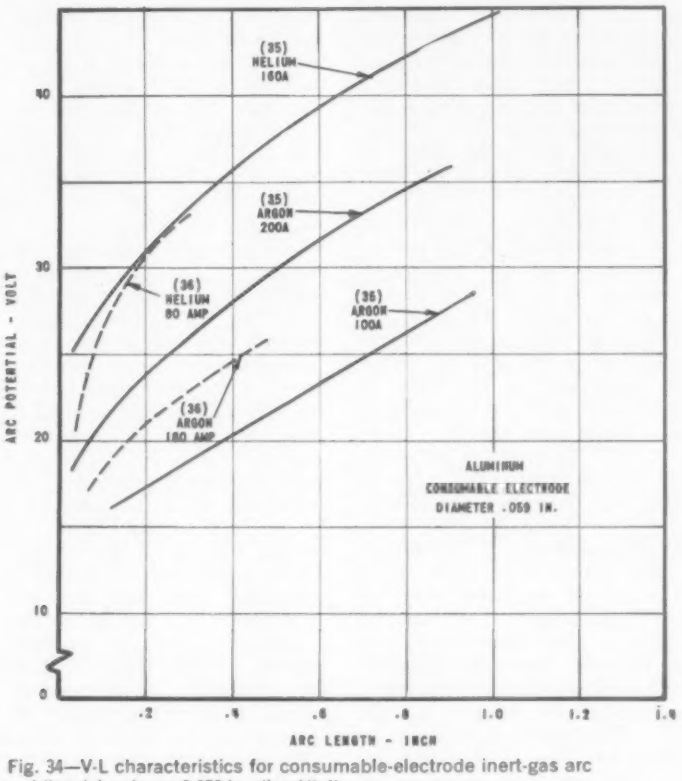

Fig. 34—V-L characteristics for consumable-electrode inert-gas arc welding (aluminum 0.059 in. diam)[35, 36]

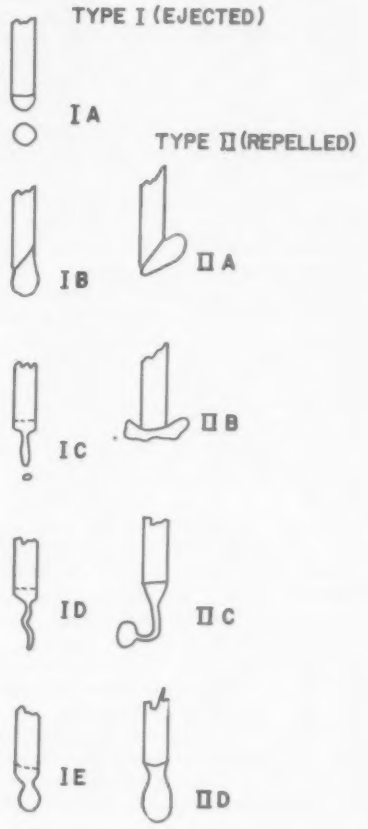

Fig. 36—Types of metal transfer

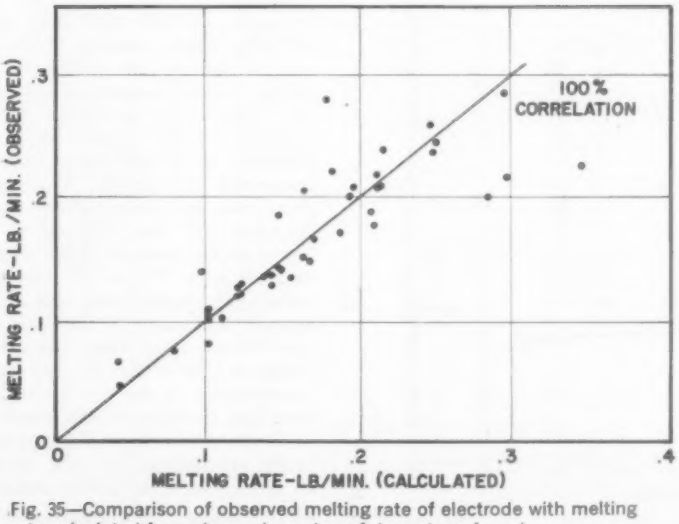

Fig. 35—Comparison of observed melting rate of electrode with melting rate calculated from size and number of drops transferred

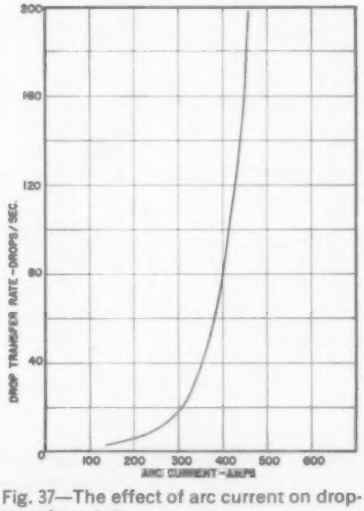

Fig. 37—The effect of arc current on drop-transfer rate[38]

ages and electrode extensions. The majority of the films were taken with a back lighting technique which obscured the arc but shows the metal transfer in silhouette. Only steel electrodes were used; hence, the following observations and calculations are restricted to this material.

Mode of Transfer. The films show a considerable amount of metal being transferred in the form of large droplets (0.02 to 0.2 in. in diam). But, the question remains as to whether or not an additional amount of metal is transferred as vapor or as tiny invisible droplets (spray). This question can be resolved by comparing the known melting rate for each case with a calculated melting rate which considers drop transfer alone. This calculation can easily be made by measuring n, the number of drops being transferred per second, and r, the average radii of these drops. Then, $4/3\ \rho\ r^3$, where ρ is the weight density of the molten-electrode material, is the amount of metal transferred by one drop and $4/3\ \rho\ r^3 n$ is the amount of metal transferred by n drops in one second. This can be converted to melting rate in lb/min by a simple factor. There is an inherent error made by the use of this formula because the drops are not all spherical. For particularly large drops, the shape is ellipsoidal. In the cases where the shape of the drop was observed to be definitely ellipsoidal, the volume of an ellipsoid was used in the calculation instead of the volume of a sphere. The observed melting rate is plotted against this calculated melting rate in Fig. 35. If the transfer was solely by means of drops and if the calculation were perfectly correct, the points would fall along the line labeled 100% correlation. It is to be noted that, if the error in measuring r is $\pm 10\%$ the error in n is $\pm 5\%$; for example, the maximum error in the melting-rate calculation will be $\pm 35\%$. In the data which were observed, the three points on the right of the ideal line most in error were points for tests in which large ellipsoidal drops occurred with low drop rates. As a result of these data, it can be concluded that over 80% of the metal transferred is in the form of drops.

Types of Transfer. Transfer occurs by the melting of the end of the electrode and the passage of the molten metal to the puddle across the arc space. In argon and argon with 5% oxygen with reverse polarity, the metal will be transferred principally in the form of large or small globules traveling at a speed faster than gravity. Since the transferring metal is propelled across the arc space, this type of transfer may be called the ejected type, Type I (Fig. 36). The globules in welding with CO_2 shielding, and often with other gases with electrode negative, may be large ($^1/_8$ in. diam). They are not propelled to the crater with any given velocity; instead while the globule is attached to the electrode, it appears to be repelled by the crater. This type of transfer can be designed as Type II, the repelled type. This, then gives us two broad classifications of transfer which have been encountered in consumable-electrode inert-gas arc welding. This transfer may be further described by designating the characteristic shape of the end of the electrode. In the simplest case, the spherical drops form at the end of the electrode and are pinched off as shown in Type I (A). After the drop has been pinched off, the end of the electrode is blunt and another drop begins to form. At the lower currents in argon and in a gas mixture containing 50% argon and 50% nitrogen, the drops were as large as, or larger than, the diameter of the electrode. The first modification of this type of transfer is that shown in Fig. 36 (IB). This is similar to the first type, except that the liquid-solid boundary is slightly tapered. The arc seems to rise higher on one side of the electrode than on the opposite side. The sloping boundary is not necessarily associated with long electrode extension. Conditions may be observed in which there is a gradual change from this type of transfer to that shown in Fig. 36 (IC) in which a thread projects downward from the electrode with the drops forming at the end of the thread. It was noted, that in all low-current tests using argon with 5% oxygen as the shielding gas, that the behavior was either of Type IA or Type IB condition. As the current was raised, for the Type IA condition, the electrode became more pointed than at lower currents. At still higher current, Type IC developed. The drops formed at the end of the thread resembled a jet of water breaking up into a chain of small drops. In a few cases at higher currents with direct-current straight polarity, the straight thread was replaced by a wavy projection from the end of the wire with drops forming and releasing from the end of the thread. This type of transfer was designated as Type ID (Fig. 36). In Type II, the transfer of the molten drop was radically different than that encountered in Type I. The molten drop rises as a large globule along the side of the electrode. The liquid-solid junction was inclined as shown in Type IB, probably because the liquid drop was pressed against one side of the electrode. Just before separation, the drop is connected by a narrow neck to the lowest point of the electrode. The detached globule usually short circuits the electrode in the process of being transferred to the puddle. In some cases, explosive action of this large globule would shatter the drop before detachment, Fig.

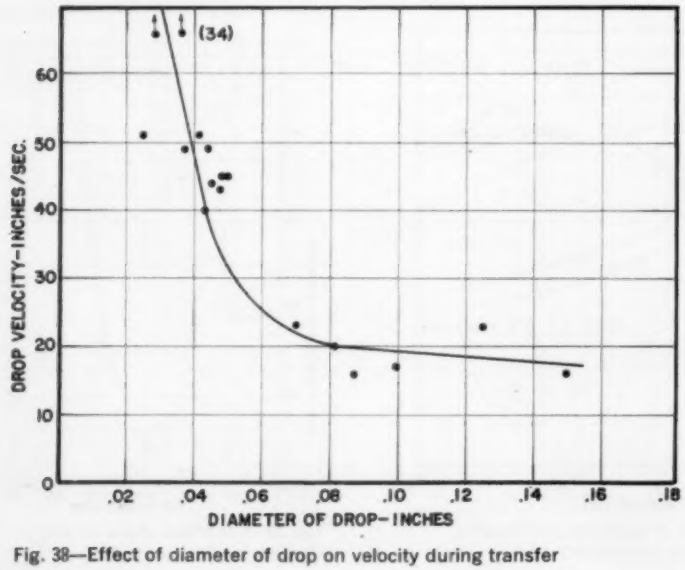

Fig. 38—Effect of diameter of drop on velocity during transfer

36 (IIB). Figure 36 (IIC) indicates an interesting type of experimental transfer. The large drop with direct current reverse polarity was supported above the puddle by a thread of molten metal. Eventually, the thread was lengthened so that the drop short circuits to the puddle and the thread was broken by fuse action and the remainder of the thread drew back to the electrode and the process repeated.

This short-circuiting action occurred in two ways. First, before separation as we just described, the drop may contact the puddle and the arc would be reignited when the thread connecting the electrode and the drop was broken by a fuse action. Generally, this type of action requires a low-voltage welding technique. Small drops which were less than 0.05 in. in diam never produced short circuits in these tests. The wavy projections shown in Fig. 36 (ID), which were obtained at the end of the electrode at high currents, sometimes shorted to the puddle and disintegrated under fuse action. In no cases were the straight threads shown in Fig. 36 (IC) associated with shorting. It is interesting to speculate as to the reason why this type of transfer did not show any shorting. In one of the films, a thread was observed with a dimension of 0.010 in. diam and 0.119 in. in length. Assuming the resistivity of liquid steel to be 200×10^{-6} ohm cm, the resistance of the thread can be calculated as 0.119 ohms. At 410 amp, the resistive drop along the thread would be 48 v. In this case, however, the arc voltage was 29 v, hence little current was carried by the thread, most of the current being drawn by the arc from close to the solid end of the electrode. In a similar manner, fuse action never occurred in these tests under the conditions of Fig. 36 (IE). The arc transferred to the end of the electrode before the drop separated. In a few cases, short circuiting occurred by the drop making contact with the electrode after striking the puddle. It is important to note, that in these tests short circuits were not observed in about 75% of the tests.

In a number of cases, long drops such as shown in Fig. 36 (IIE) were observed. These drops were such that the length was a multiple of the diameter of the electrode. Some of the drops were 0.3 in. in length, and often this type of transfer accounted for short circuiting. The long drops were accompanied by shallow craters and may represent the transition phase between the large spherical drops of lower currents and the threads characteristic of high currents.

When the arc and drop were quiet, the drops traveled in a straight line vertically down to the puddle. With the large, Type II drops, an agitated condition existed in which the drops spun and turned end over end often in a haphazard manner. The tiny globules resulting from exploding drops were flung from swinging threads and usually traveled outside the weld zone.

The observation of the puddle action which was possible in many of the films showed violent agitation and surging back and forth with rimmed electrodes. Sometimes puddle ejections were present. It appears that oxidizing conditions promote puddle ejections. This condition, of course, exists with CO_2 as a shielding gas.

The depth of the crater was difficult to estimate in many of the cases but very shallow craters were

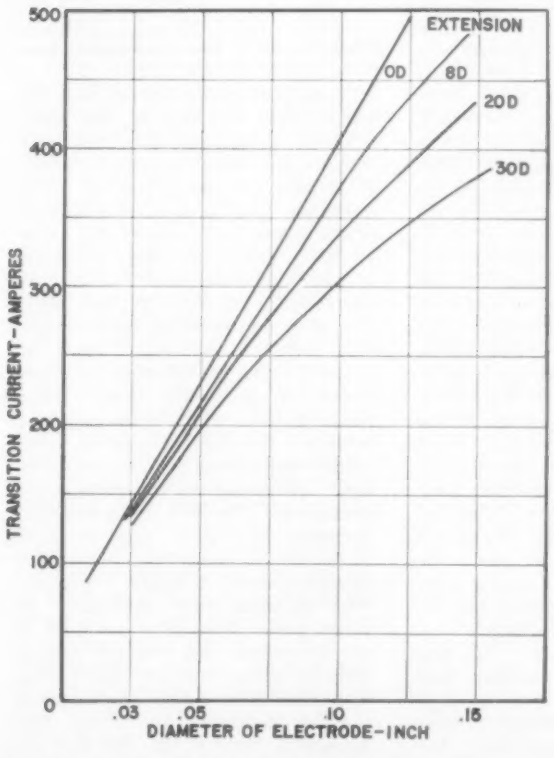

Fig. 39—Effect of electrode diameter and electrode extension on transition current from drop to spray transfer

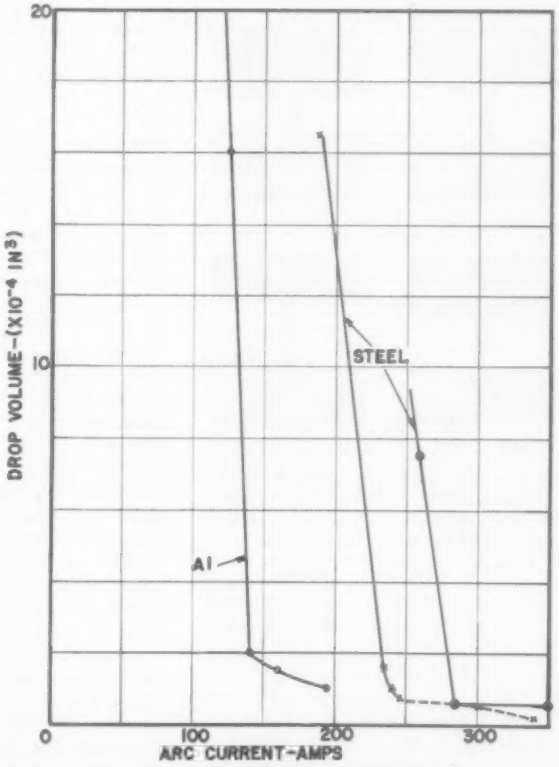

Fig. 40—Comparison of transition current for aluminum and steel electrodes[8, 27]

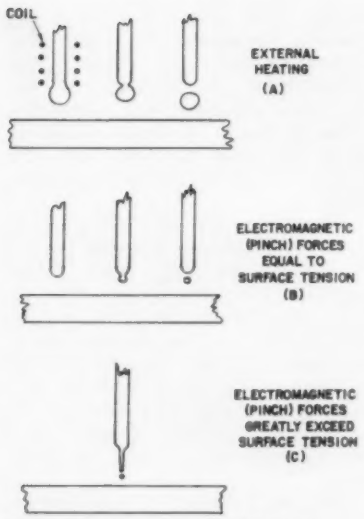
COIL
EXTERNAL HEATING (A)
ELECTROMAGNETIC (PINCH) FORCES EQUAL TO SURFACE TENSION (B)
ELECTROMAGNETIC (PINCH) FORCES GREATLY EXCEED SURFACE TENSION (C)

Fig. 41—The transfer of metal drops is controlled by electro-magnetic (pinch) forces and surface tension[36]

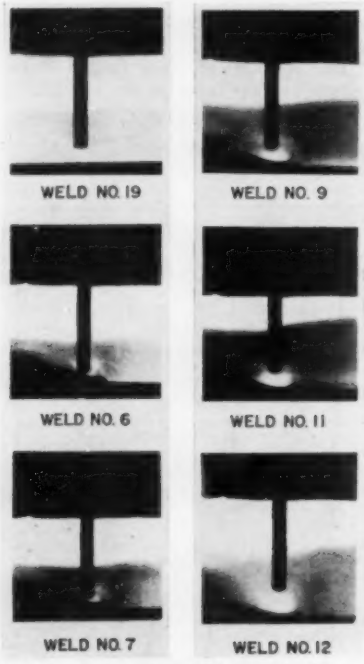

Fig. 42—X-ray radiographic examination of submerged-arc welding zone showing effect of increasing voltage on distance between electrode and weld metal[42]

Weld no.	Voltage	Shortest distance of electrode to weld metal, in.
19	None	...
6	25	0.034
7	30	0.068
9	35	0.119
11	40	0.204
12	45	0.340

easy to detect. Shallow craters were favored by low-current, direct-current straight polarity, and argon shielding gas. The pinch force seems to provide some indication of the depth of the crater. For example, if the crater is assumed to be $^3/_{32}$ in. in diam, the pressure due to pinch effect with 200-amp current is 1140 dynes per square centimeter. This is equal to a ferrostatic pressure of 0.066 in. The corresponding depth with 400 amp is 0.26 in. These estimates approximate those measured experimentally.

Many drops exploded before separation from the electrode. In general, there are three types of explosions: (*a*) sudden local bursting of the side of a drop which might be described as a blowout; (*b*) extremely rapid bubble formation and explosion, this type of explosion is sometimes encountered at a speed faster than a single frame or in less than 0.003 sec; and (*c*) relatively slow bubble formation followed by explosion. In one case, a globule of liquid metal 0.069 in. in diam remained at this diameter for 45 frames, then grew to 0.32 in. in diam in 5 frames and burst. This bubble was attached directly to the solid electrode. If it is assumed that the liquid globule originally was solid and that the enlarged bubble contained a gaseous center with no additional metal, the thickness of the wall can be calculated to be 0.0002 in. just before explosion. The volume occupied by the drop increased 100 times during expansion. It is suggested that this reaction must have resulted from a gaseous reaction and could not have been due to the reaction with an outside inclusion. In studying the surface of the drops, in some cases the films indicated a turbulent surface, in others the surface was smooth and quiet. In some cases, the drops were smooth and quiet although the puddle in the crater was agitated. The motion of the arc will vary. Sometimes there was a rapid lateral movement. The arc flickered from the drop onto the solid electrode. The arc generally terminated on the under surface of the drop when the drops were large; when the drops were small, the arc terminated on the solid electrode above the drop.

Drop Rate and Size. Melting rates computed from measured drop rates and diameters were in good agreement with measured melting rates with a few exceptions. The exceptions were those in which there was considerable range in drop diameters. The important factors in controlling drop rate and size are current, electrode diameter and extension, and shielding gas. As has been noted by other investigators, the current range in which the mode of transfer change from large drops to small drops in argon and argon with 5% oxygen was:

Electrode diam, in.	Current range, amp
$^1/_{16}$	200–250
$^3/_{32}$	300–350
$^1/_8$	350–500

These current ranges suggest that drop size is influenced by surface tension and pinch forces which oppose each other. When the pinch force exceeds the surface tension, small drops are formed. It is possible to calculate approximately the surface tension which exists for comparison with the pinch effect in the current range shown above.

Electrode diam, in.	Surface tension force, dynes	Pinch force, dynes
$^1/_{16}$	420	250
$^3/_{32}$	630	530
$^1/_8$	840	1000

These calculations show that the pinch force becomes of the same order of magnitude as surface tension in the current range in which drop rate increases rapidly. The shielding gas has an important bearing on drop rate and size. In CO_2 gas, the drop rate for $^1/_{16}$-in. electrode was low at all currents from 210 to 390 amp. CO_2 may increase the surface tension force or may itself exert an upward force at the high voltages which are generally used. Other minor factors which influence drop rate are electrode extension, electrode composition, polarity and voltage. Increasing the electrode extension from $^3/_4$ to $2^5/_{16}$ in. in one case increased the drop rate from 10 or 12 to 28 drops per second on direct-current straight polarity. The melting rate increased for these tests from 0.71 to 0.95 lb per thousand amperes per minute and the drop size decreased from 0.15 to 0.10 in. On direct-current reverse polarity, the drop rate increased from 40 to 160 and the drop diameter decreased from 0.069 to 0.0592 in. for a similar change

in electrode extension. Increasing the current 40 to 50 amp would have caused the same increase in drop rate. The increase in melting rate due to the increased current, however, would have been only 20% of the increase produced by the increase in extension. The effect of extension on drop size has not been explained, although tests indicate that increased extension will increase the drop rate.

The rate of transfer of drops is dependent upon the welding current; the drop transfer rate increases rapidly as a certain transition current is reached. A typical relation is shown in Fig. 37 with a transition current at approximately 300 amp. As shown in Fig. 38, this transition current is accompanied by a decrease in the diameter of the drops and an increase in the velocity of the drops in their transfer across the arc zone.

Data have been presented by Lesnewich[26] which permit prediction of the current for transition from large to small drops, for steel electrodes with a change in diameter and electrode extension (Fig. 39) for argon with 1% oxygen for shielding.

That the transition from large to small drops occurs at a lower current for aluminum has been shown by a number of investigators[27, 8] (Fig. 40).

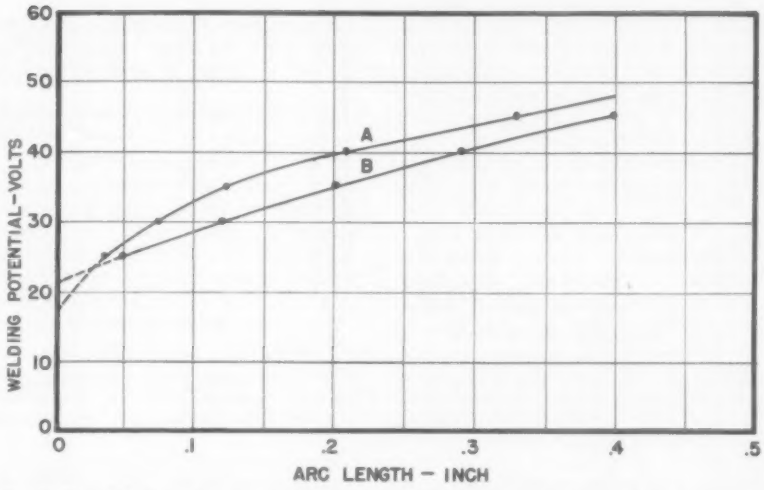

Fig. 43—Length of arc increases with welding potential for two submerged-arc compositions at 600-amp current

Forces Acting on Drop

In order to determine the forces that might act on the drop while it is in the gap, the possibility of a number of conditions was examined. The drop may possibly be charged with the same sign charge as the electrode from which it is released; the drop may then be accelerated by electric fields for a short distance and then move in a force-free way with constant velocity across the arc distance. Since it was observed that the velocity was constant and independent of time, this possibility appeared to be remote. It was concluded that electrostatic forces were not an important factor in the transfer since neither the charge nor the electric-field strength were great in the welding arc.

The unsatisfactory results of attempts to account for the motion of the drop by forces exerted on the drops in the arc plasma led to a consideration of the forces that are exerted on the drop at the electrode. If the balance is of proper magnitude and direction, the motion of the drop across the gap is easily accounted for as a force-free motion. The major forces acting on the drop while it is still attached to the electrode[28] are the gravitational force (weight), surface tension, which is directed toward the electrode, the electro-magnetic forces (pinch effect) and the "arc forces," which may be due to particle recoil and are directed toward the electrode.

Gravitational Force. The gravitational force is the simplest to calculate and remains essentially constant during the period in which the droplet is transferred, and can be positive or negative depending upon the position of welding. It is recognized by welding men that, for overhead welding, a condition exists which is essentially the same as horizontal welding as far as the transfer process is concerned, except for large drops. Compared to the other forces to be considered, gravitational force is small and is practically negligible for drops of diameters smaller than the diameter of the electrode.

Surface Tension. Surface tension is believed to be the major force preventing the transfer of the drop from the electrode. To illustrate the magnitudes involved, consider that a molten drop of steel is suspended from a $^1/_{16}$-in. diam electrode. Then

$$mg = \pi d\sigma$$

where:

m = mass of drop
g = gravitational constant
d = diameter electrode
σ = 1700 for steel at 1570° C

Also, if the drop is spherical

$$m = 4/3\ \rho r^3$$

where:

ρ = density
r = radius of drop

By calculation, the radius of the drop is found to be approximately 0.1 in. The maximum drop radius observed in the experiments with the $^1/_{16}$-in. electrode was 0.10 in. In the simpler experiment by Spoelhof[29] the largest drop observed had an estimated diameter of $^1/_4$ in.

Electro-magnetic Forces (Pinch Effect). It is well known that two parallel conductors carrying current in the same direction will be attracted to each other. A single conductor can be considered as consisting of a number of parallel current-carrying filaments. Therefore, a force is exerted on the conductor carrying a current, in such a direction as to decrease its radius. This force is not often encountered in experience because of the rigidity of most conductors, but it is important for liquid conductors such as the molten end of the electrode in consumable-electrode arc welding.

There are actually two electromagnetic forces to consider. The first arises in a manner described above. The pressure due to the radial force creates a longitudinal force in the liquid conductor. This force is independent of the size of the conductor. A second electromagnetic force occurs because of the change in self-inductance in a conductor of varying cross section. In a nonrigid conductor like the molten globule at the end of a welding electrode, a force will be exerted tending to separate the conductor due to the electro-magnetic forces. There is some difficulty in applying and calculating these

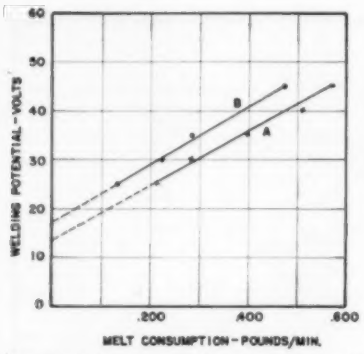

Fig. 44—Melt consumption increases with welding potentials for two submerged-arc compositions

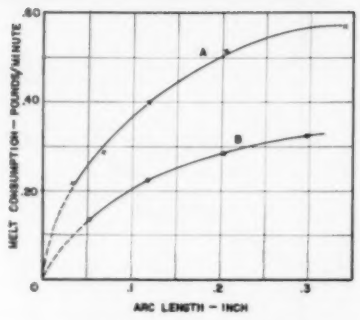

Fig. 45—Relation of arc length and melt consumption for two submerged-arc compositions

forces until the current path is understood. Observations made from the high-speed films show that the arc tends to cover the bottom half of the drop, if the drop is larger than the electrode, but climbs up and surrounds the drop if it is smaller than the diameter of the electrode. In the first case, it can be considered that the current is uniform everywhere through the drop but, in the second case, some adjustment must be made since all the current does not flow through the drop. The effective current can be taken as $(d_1^2/d_2^2)I$ where I is the arc current, d_1 is the diameter of the drop, and d_2 is the diameter of the electrode. On this basis, it can be shown that for a 200-amp arc, the electro-magnetic force may be in the order of 200 dynes. This is to be compared with the gravitational force which for a drop of $^1/_{16}$-in. diam is approximately 25 dynes.

Under some conditions, there is another considerable force tending to hold the drop to the electrode, a force which appears to be due to some process in the arc. In many cases, this force appears to be small compared to the surface-tension force and the electro-magnetic forces. The cause of this force is unknown at this time, but it may be due to the recoil of positive ions leaving the electrode.

Motion of the Drop

Under some conditions, drop transfer is by short-circuiting, that is the drop touches the weld puddle while still partly attached to the electrode, the drop being torn from the electrode by the almost immediate vaporization of metal at the neck connecting the drop and the electrode. In most cases, however, including welding with normal conditions, (M-5 gas, $^1/_{16}$ in. carbon-steel electrode, 200–300 amp, 30 v), the drop leaves the electrode and travels to the weld puddle in free flight. The motion of the drop in the space between the electrode and the weld puddle was studied in an attempt to localize the forces producing transfer. Measurements of distance traveled as a function of time were made from the films for a number of drops. The result, in every case, was that the distance traveled was directly proportional to time; in other words, the drops moved with constant velocity from the electrode to the weld puddle. The time of flight was so short (approximately $^1/_{200}$ sec), that the effect of gravity upon the motion was negligible. After $^1/_{200}$ sec, the velocity of drop would be 1.28 ips under the influence of gravity alone. This is small compared to the observed velocities of 15 to 50 ips.

There are three ways to account for the constant-velocity motion which was observed: (1) the drop is expelled as from a gun and no forces act upon the drop thereafter. (2) The drop is acted upon simultaneously by an accelerating force and by a velocity-dependent retarding force after it is separated from the electrode by some force such as the pinch effect. This second mode of motion is exemplified by a rain drop falling through the air—it is accelerated by the gravitational force and retarded by the viscous retarding force of the air. After a certain time, the rain drop reaches an essentially constant terminal velocity which has been mathematically described by Stokes' Law. (3) The drop is acted upon by an accelerating force which is a function of the velocity of the drop such that the force on the drop becomes zero when the drop reaches a certain terminal velocity.

To determine the possible forces in the arc stream, a gas-shielded horizontal arc with a tungsten cathode and water-cooled carbon anode was set up by Spoelhof[39] so that a "cold" steel electrode could be fed vertically into the arc. The steel electrode carried no current. It was observed that the drops which formed at the end of steel electrode were deflected toward the anode when they left the rod. The strength of the deflecting force increased with current. The distance-time measurements made of the drops in the consumable-steel arc, however, showed little change in drop velocity with polarity, other conditions being the same. It is realized that the inert-gas consumable-electrode welding arc does not necessarily exhibit the same characteristics as the tungsten arc.[40, 41] The velocity observed for the droplets seemed to be independent of every factor except drop radius. Figure 38 shows indirectly that the terminal velocity is related to the diameter of the droplet.

Spatter

There are four sources of spatter in the inert-gas consumable-electrode welding zone: (1) gas evolution, either from the electrode, causing exploding drops, or from the puddle, causing puddle ejections; (2) contact or fuse effect, due to short circuits or the explosive disintegration of thin connections; (3) globular instability due to excessive size producing a disintegrating drop; and (4) momentum effect caused by the swinging motion of a moving arc spot producing erratic transfer and multiple-particle transfer. In a general way, the smaller particles of 0.01 in. and less, which occur as spatter, develop from exploding and disintegrating drops, puddle ejection, erratic transfer and multiple-particle transfer. Larger spatter particles in the range of 0.02 to 0.03 in. result from contacts while still larger spatter in the $^1/_8$- to $^3/_{16}$-in. range result from erratic transfer, disintegrating drops and occasional contacts.

General Features of Metal Transfer

As a result of this discussion, the general features of metal transfer in the consumable-electrode welding arc can be described. In Fig. 41a, a hypothetical case is shown in which zero current and external heating is employed. Drops will form and finally separate when a drop weight overcomes surface tension. At very low currents, or with the water-cooled electrode, there is no metal transfer. The

heat transmitted to the electrode by the arc is dissipated without fusion. As the current is raised beyond the maximum for no transfer, metal transfers first as short-circuiting masses. In the early stages of formation, the drop occupies a major part of the transfer space. Voltage cannot be increased without extinguishing the arc. Fully developed drops do not occur. The melting rate is low because a large portion of the arc heat is dissipated by the electrode through thermal conduction. At the currents and electrode diameters used in inert-gas consumable-electrode arc welding, the electrode is fed at a fairly high rate. Thermal conductivity plays a very negligible role. Drops form at the end of the electrode and transfer. At higher temperatures, the surface tension is lowered and the drop becomes smaller. As current is raised, the drop rate would increase proportionately to the increase in temperature. When electro-magnetic forces become significant and outweigh surface tension, the pinch force constricts the molten end of the electrode. Drops are pinched off before they attain the size permitted by their surface tension (Fig. 41b). At high pinch forces, Fig. 41c, the end of the electrode is constricted at all times. A jet of liquid metal squirts from the end of the electrode and travels at high speeds and like any high-speed jet breaks up into small droplets. The contribution of electro-magnetic forces to these droplets is indirect. The high-speed jet is created by electro-magnetic forces but the breakup of the jet into droplets is probably a characteristic of atomization and not the result of electro-magnetic forces.

Relationships in Submerged-arc Welding Zone

In the submerged-arc welding process, special techniques have been used to study the welding operation. The usual relationships of electrode melting rate (Fig. 25) and flux consumption are readily determined. Likewise, the penetration and weld-metal geometry are amenable to control by selection of welding techniques. Many of the factors readily observable in open arcs cannot be studied.

Recognizing that the factors influencing the submerged-arc welding zone are complex in nature, it is apparent that the available welding data are difficult to analyze. It is not possible to isolate the causes of many observed welding results and identify them as chemical reactions, electrical effects or other physical changes. An investigation has been carried out by Webb[42] in which the arc spectra from the submerged-arc zone have been studied in order to obtain an indication of temperatures and other phenomena in the submerged-arc weld zone. The problem of transmitting radiation out of the arc zone to the optical system of the spectrograph was overcome by using an optical window of fused quartz. These windows, $1/4$ in. thick, $1/2$ in. high and 3 in. long, were placed parallel to the welding-travel direction in such a way that the molten flux and weld metal cast against the quartz plate. Good optical transparency was retained during exposures so that it was possible to observe visually the motion of the arc. The welding conditions selected were 400 amp, 35 v and 20 ipm travel. The quartz window was clamped $1/32$ to $2/32$ in. from the path of the $1/8$-in. diam electrode.

As a result of these tests, it was determined that the submerged-arc plasma is essentially a slightly ionized vapor column with a core temperature of about 6000° K. This central core is surrounded by thin concentric zones at lower temperatures with a steep radial-temperature gradient terminating at an indefinite vapor-liquid phase boundary at a boiling temperature representative of the flux components. Only ions of single charge were found in the arc, the temperature being too low to excite a significant number of atoms to higher levels of ionization.

Spatial Relationships in Submerged-arc Zone

The welding zone for submerged-arc welding may be studied by means of X-ray radiographic examination through the submerged-arc flux. An X-ray shadowgraph of the electrode, crater and base plate has been used by a number of investigators[21, 43–45] for determining the spatial relations in submerged-arc welding. Results typical of those obtained by Wilson[43] are shown in Fig. 42 for tests with a submerged-arc composition with 600 amp and 10 ipm travel. A plot of the shortest distance between the electrode and weld metal is shown in Fig. 43. From these

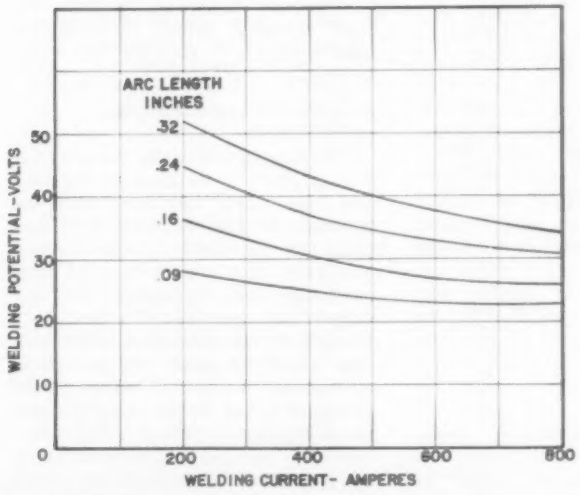

Fig. 46—Relationship of welding current (electrode negative) and voltage to arc length for submerged-arc process[27]

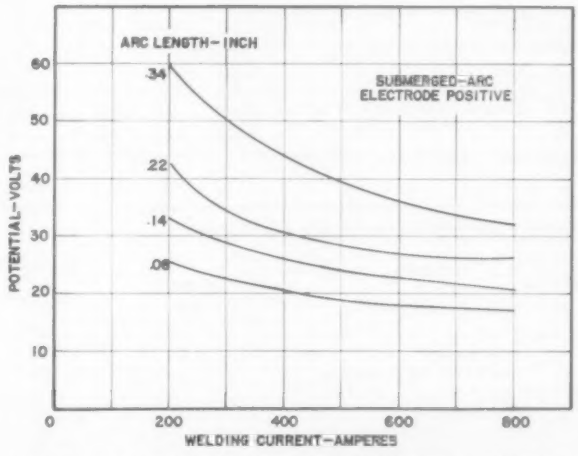

Fig. 47—Relationship of welding current (electrode positive) and voltage to arc length for submerged-arc process[27]

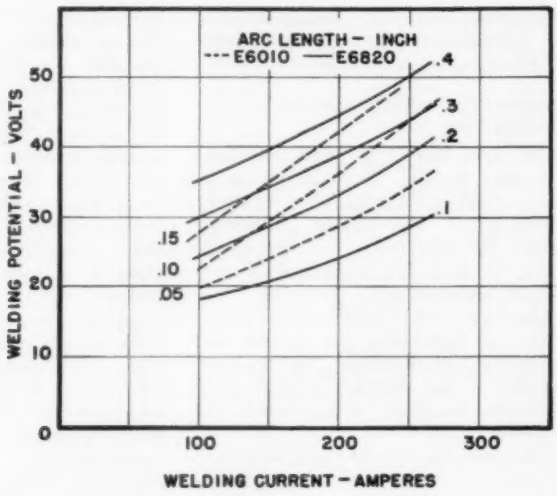

Fig. 48—Relationship of welding current and voltage to arc length for covered electrodes of E 6010 and E 6020 types[75]

welding tests, it is also possible to observe the effect of voltage on flux consumption (Fig. 44) for two of the submerged-arc compositions shown in Fig. 43. The relationship of flux consumption and distance between the electrode and the plate is shown in Fig. 45; this plot indicates that zero flux consumption should occur at zero arc space when the electrode touches the plate and no plasma exists.

The X-ray technique also has been used by Tikhodeev[45] to study the submerged-arc characteristics. The volt-ampere characteristics for both electrode negative (Fig. 46) and electrode positive (Fig. 47) were studied. In further analysis of these tests, it is suggested that a minimum voltage should be obtained for submerged-arc welding similar to that noted for the inert-gas tungsten-arc process as shown in Fig. 9. The fact that the submerged-arc process, as shown by these data, decreases in voltage for a given electrode-to-plate distance with increasing current is unexplained. The tests reported by Wyant[46] indicate the usual increase in voltage with current for covered electrodes (Fig. 48).

It is now possible to compare the voltage-spatial relationships for the inert-gas tungsten-arc and the submerged-arc welding processes. This is done in Fig. 49 for tests using 600-amp welding current. For comparison, the voltage-spatial relationship and the apparent arc resistance for these tests are given in Table 5.

Table 5—Total Welding Voltage at 600-amp Current

Distance, in.	Tungsten-arc argon	Submerged-arc: Russian flux DCRP	Submerged-arc: Russian flux DCSP	Submerged-arc: American flux, DCRP Grade A	Submerged-arc: American flux, DCRP Grade B
0.05	12.8	17.0	20.5	29.0	25.5
0.10	14.0	19.0	24.0	33.5	28.0
0.20	16.5	27.0	30.5	39.6	34.8
0.30	18.5	34.0	36.5	47.5	40.2
Apparent arc resistance—ohms (R = E/I)					
0.05	0.021	0.028	0.034	0.048	0.042
0.10	0.026	0.032	0.040	0.055	0.046
0.20	0.027	0.045	0.051	0.066	0.058
0.30	0.032	0.056	0.061	0.079	0.067

Table 6—Energy Distribution in Arc Welding[49]

Process	Covered	Submerged-arc	Submerged-arc
Current, amp	350	280	750
Volts	22	28	36
Travel, ipm	4.6	9.8	16.4
Electrode diameter, in.	5/32	5/64	5/16
Heat Utilization			
Melting electrode, %	33	29	27
Melting base, %	8	20	45
Total useful energy, %	41	49	72
Melting flux, %	7	37	25
Losses, %	52	14	3

Distribution of Energy in Welding Arc

The distribution of energy in the welding arc has been studied by a number of investigators.[21, 47–49] An early attempt was made by Alexander to determine the distribution of energy in the electric arc by the calorimetric method. In Alexander's tests with iron, used for both the anode and cathode, the energy developed at the surface of the anode was practically equal to that developed at the cathode. His tests also pointed out that various materials used as a coating on the electrodes may affect the distribution of the energy.

A further study by Sandelowky[48] carried out probably with a bare wire at a low current and slow travel indicated that 26% of the energy was used in melting the electrode and base metals. A qualitative study by Jackson and Shrubsall[21] indicated that the energy utilized in forming the weld nugget for both covered electrodes and submerged-arc welding ranges from 20 to over 50% of the total energy input, the energy utilized increasing with current and speed of travel. Tests reported by Paton,[49] Table 6, show a utilization of heat in melting the electrode at a higher value than most other investigators. The high current used in the tests on 3/16-in. diam covered electrode may be a factor in the high melting rate; in a like manner, an electrode extension greater than 8 times the electrode diameter would increase the heat utilized in melting the electrode to a value higher than normal.

Arc Force Between Electrode and Plate Metal

The magnitude of the force which is exerted by a welding arc against the base plate has long been of interest to the welding field because of its effect on the molten metal in the crater beneath the electrode and, therefore, on the shape and quality of the bead. Doan[50, 51] obtained data with both bare and covered 5/32-in. diam electrodes in air, helium and nitrogen using both straight- and reverse-polarity power. He measured the arc force by means of an upright torsional balance on which the arc force was transmitted to a delicate helical spring. The maximum current used by Doan was 220

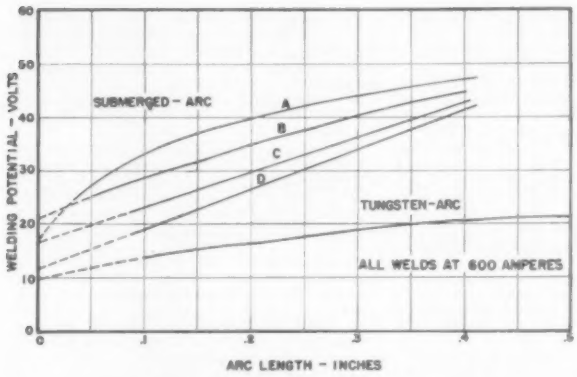

Fig. 49—Comparison of increase in arc length with welding potential for four submerged-arc and a tungsten-arc welding test using 600-amp welding current

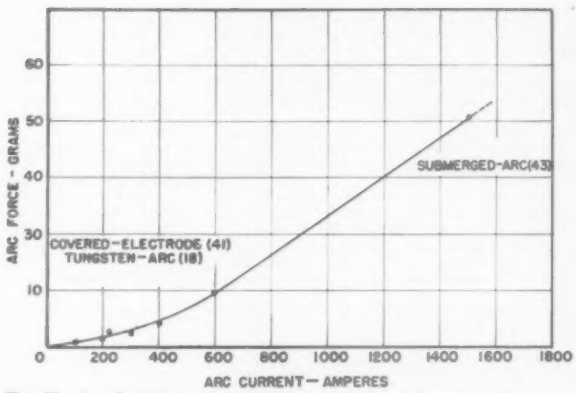

Fig. 50—Arc forces increases with arc current for covered electrode, tungsten-arc and submerged-arc processes[18, 41, 43]

amp. Doan made the following observations: (1) the arc force was about the same magnitude regardless of the polarity, (2) the amount of force varied to some extent with different gaseous media, (3) the arc force did not of itself create a crater by pushing liquid weld metal aside, as evidenced by the fact that in his tests no craters were formed when welding in inert atmospheres. The results are shown in Table 7.

Tests have been reported by Wilson[52] in which the arc force was measured for a submerged-arc weld deposited using 1550-amp ac, 41 v and 11 ipm with a $^5/_{16}$-in. diam electrode. A continuous record was taken of the time of welding and balance readings. The arc force was found to be 40.5 g. Olsen[19] in his studies of the inert-gas tungsten welding arc in argon measured the total anode force for currents ranging from 100 to 300 amp. These data are also shown in Table 7 and Fig. 50. Rohloff[11] used a floating cathode to measure the arc force for a carbon arc. Tests were carried out for 200 and 300 amp. The results are included in Table 7.

Table 7—Summary of Arc-force Studies

Current, amperes	Arc force—grams			
	Doan[51]	Wilson[52]	Olsen[19]	Rohloff[11] (Carbon arc)
75	0.59	...	...	...
100	0.59	...	0.25	...
120	0.79	...	...	...
125	0.71	...	...	...
130	0.80	...	...	...
150	0.94	...	0.48	...
150	1.14	...	...	...
160	1.25	...	...	...
200	...	...	1.18	0.50
220	2.63	...	...	...
220	2.73	...	...	...
250	...	...	1.75	...
300	...	...	2.10	1.2
1550	...	40.5	...	...

Discussion

The more complicated consumable-electrode welding arc has not been subject to a thorough fundamental study. In this case, engineering application has forged ahead of a full understanding of the welding-zone characteristics. The broad field, however, is receiving widespread attention and active investigations with a recognition of the important variables will soon result in a more complete knowledge of the characteristics. A clarification of the effect of welding technique on melting rate is rapidly forming, particularly with the recognition of the importance of the I^2R heating in the electrode extension. Consideration of the temperatures in the weld zone has shown temperatures in the 6000° C (approximately 10,000° F) range in the arc plasma; the weld metal in the crater has been reported by a number of investigators at less than 2000° C (3500° F). The heat transferred to the base plate depends upon the speed of travel and cooling in the heat-affected zone and is controlled mainly by the area of molten weld metal. It has been pointed out that the transfer of molten metal from the consumable electrode is mainly controlled by the surface tension and electromagnetic force (pinch effect) acting at the tip of the electrode.

The spatial relationship of the electrode and work probably control the action of the arc on the base plate. Although, in any particular test condition, voltage will increase as the electrode-to-plate distance is increased, the rate of change will depend upon the process and level of current which is used. This in turn will affect the arc performance. The actual geometry of the arc zone may be a more fundamental parameter than welding voltage.

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RESEARCH NEWS

Variables Affecting Fatigue Life of Metals

The report, *Qualitative Aspects of Fatigue of Materials*, investigates the variables affecting the fatigue life and strength of metals. Another report prepared during the same study deals with the fatigue of high-strength steels at room temperature. The two reports are:

Qualitative Aspects of Fatigue of Materials. H. N. Cummings, Curtiss-Wright Corp. for Wright Air Development Center, U. S. Air Force. September 1959. 263 pp. (Order PB 161145 from OTS, U. S. Department of Commerce, Washington 25, D. C., $4.00.) This study seeks ways to insure a satisfactory life from metal parts and structures by investigating the manner in which metals are weakened or fatigued. The variables affecting the fatigue life and strength of structural metals are discussed qualitatively, and theories on the mechanism of fatigue are reviewed.

Investigation of Fatigue Properties at Room Temperature of High-Strength Steels Having High Tempering Temperatures. H. N. Cummings and others, Curtiss-Wright Corp. for Wright Air Development Center, U. S. Air Force. September 1959. 105 pp. (Order PB 161144 from OTS, U. S. Department of Commerce, Washington 25, D. C., $2.50.) The fatigue properties of high-strength steels having high tempering temperatures are investigated at room temperature. The report makes a statistical investigation of the fatigue characteristics, primarily of missiles and other flight vehicles. Emphasis is placed on testing materials of higher strength-to-weight ratios designed for high operating temperatures.

Technical Reports

A technical report describing development of a new weld-metal for welding light gage, high-yield-strength structural steel to withstand dynamic loading at low operating temperatures has been published. Also available is a report on the charpy-V transition temperatures of ferritic iron alloys.

Development of Notch-ductile Stress-relieved Weld-metal for the Fabrication of Dynamically-loaded T-1 Steel Structures. J. S. Kobler, Naval Gun Factory. April 1959, 64 pages. (Order PB 151990 from OTS, U. S. Department of Commerce, Washington 25, D. C., $1.75.) A problem in welding light gage, high-yield-strength structural steel to withstand dynamic loading at low operating temperatures was solved by the Navy through development of a new weld-metal. Electrodes developed deposit compatible stress-relieved weld-metal yielding uniform energy absorption values, equivalent to those of the base-metal, through all zones across the T-1 weld-joint.

Charpy-V Transition Temperatures of Ferritic Iron Alloys: Part *2—Iron-chromium and Iron-chromium-aluminum*. J. E. Stawley, U. S. Naval Research Laboratory. August, 1959. 19 pages. (Order PB 151811 from OTS, U. S. Department of Commerce, Washington 25, D. C., 50 cents.) Mid-energy transition temperatures of a series of iron-chromium alloys containing up to 24.3% chromium, and of three series of iron-chromium-aluminum alloys containing up to 25% chromium and 6% aluminum were determined for several conditions of mechanical working and heat treatment.

Test for Hot Cracking

A laboratory test to predict susceptibility to hot cracking, particularly in various welded stainless-steel alloys is reported through *Westinghouse News* to be simple, inexpensive and much faster than other methods.

Clarence Zener, director of Westinghouse research credits researcher, F. C. Hull, with the invention called the "cast pin tear" (CPT) test. The test consists of levitation melting a 20-g sample in argon and then pouring the melt into a pin-shaped copper mold with end restraints which, during cooling, set up tensile stresses. By measuring the amount of tearing in pins of different sizes a numerical scale is made of relative susceptibility to hot cracking. Samples are compared to the scale. (cf. THE WELDING JOURNAL, **38** (4) Research Suppl., 176-s to 181-s (1959).)

Photoelastic-Coating Technique for Determining Stress Distribution in Welded Structures

Basic principles of process are presented and several applications are described to indicate the use of photoelastic-coating technique in welded structures

BY F. ZANDMAN

Part I. Description of the Photoelastic-coating Technique

Historical Development

The principle of strain measurements by coating a mechanical part with a photoelastic plastic is credited to Mesnager[1] (France, 1930), who was unable to obtain practical results with this technique since, at that time, sensitive and stable photoelastic materials did not exist. Subsequent attempts were made by Mabboux[2] (France) in 1932 and Oppel[3] (Germany) in 1936. In March 1953, Jessop (England) cited in the *Journal of the Royal Aeronautical Society* research on this subject by a British aeronautical laboratory. In July 1954, Drucker[4] (United States) presented a paper in Brussels at the Convention of IUTAM on research conducted at Brown University. Since 1953, results in both elastic and plastic ranges of deformation, applicable to any part regardless of material, size or shape, were achieved in industrial applications in France[5-7] where the photoelastic-coating technique was used as a practical tool directly in the field.

Basic Principles of the Photoelastic-coating Technique

It is well known [8,9] that, under the action of stresses, transparent materials become doubly refracting (birefringent) and if a beam of polarized light is passed through a model (under stress) made of such a material, a colored picture—from which the stress distribution can be found—is obtained. This technique is called photoelasticity.

The photoelastic-coating technique is a method of stress analysis in which the actual structure to be stress analyzed is coated with a photoelastic plastic. When a load is applied, strains are transmitted to the plastic coating, which then becomes birefringent. This birefringence is directly proportional to the intensity of strain. If a reflective surface is provided on the structure, or on the inside face of the plastic bonded to it, birefringence can be observed and measured, using a reflection polariscope. When examined in the field of white plane polarized light of the instrument, black and colored fringe patterns are seen which reveal the geography of mechanical strains in the actual structure.

The black fringes, or isoclinic fringes are the loci of points where the directions of the principal stresses are constant and are the same as the directions of the axes of polarization of the polariscope, which are known. They are visible when the polarization axes of the instrument's polarizer and analyzer are crossed. By simultaneous rotation of the polarizer and analyzer (always holding them crossed) from 0 deg to 90 deg, each point of the surface to be stress analyzed is covered at least once by an isoclinic fringe; hence the directions of the principal stresses can be determined at each point of the structure. From these isoclinic fringes, the two families of isostatics, or stress trajectories, can be plotted.

By insertion of two quarter-wave plates, each with its optical axis at 45 deg from those of the polarizer and analyzer (one quarter wave between the polarizer and plastic-coated part and the other quarter wave between the analyzer and plastic-coated part), the plane polarized light is transformed into circular polarized light. The isoclinics disappear, and only colored fringes are present in the field of observation. If a black fringe is visible in circular polarized light, this black fringe will indicate an area where the principal stress difference is zero.

The colored fringes—called isochromatic fringes—observed with polarized light traversing the plastic under normal incidence, are the loci of points where the principal stress difference $(\sigma_1 - \sigma_2)$ is constant. Stresses in the plastic are related to the birefringence measured under normal incidence by the formula

$$(\sigma_1 - \sigma_2)_p = \delta_n / 2tC^* \qquad (1)$$

and the stresses in the structure are given by

$$(\sigma_1 - \sigma_2)_m = \frac{\delta_n (E_m / 1 + \mu_m)}{2tK} \qquad (2)$$

where $K = CE_p/1+\mu_p$; K is generally obtained by calibration. Note that the maximum shear stress in the surface of the part, τ_{max}, is equal to one-half $(\sigma_1 - \sigma_2)$. Applying Hooke's laws to eq 2, it can be seen that:

$$(\epsilon_1 - \epsilon_2) = \delta n / 2tK \qquad (3)$$

Having $(\sigma_1 - \sigma_2)$ and the directions of σ_1 and σ_2, it is usually possible in important cases to determine the individual values of principal stresses mathematically. Also, along any free boundary (hole, notch, etc.) where most failures occur, the stress normal to the boundary is zero; therefore the tangential stress is given directly by the instrument. In cases where the individual principal stresses should be determined experimentally, a

F. ZANDMAN, Instruments Division of The Budd Co., Phoenixville, Pa.

* List of symbols used is given at end of paper, page 198-s.

photoelastic analysis made with polarized light traversing the plastic under oblique incidence will provide σ_1 and σ_2 in magnitude and sign.[5, 7, 10, 12] A detailed description of the oblique incidence method can be found in Reference 16.

Four basic methods of measuring the fringe value or color value (δ) using circular polarized light—hence the magnitude of principal strains or stresses in the part—are described below. These four methods are listed in order of increasing accuracy:

1. Identify the color observed, and look up its corresponding strain value in a "color-vs.-strain" conversion chart, which can be obtained by calibration.[15]

2. Find a black line or area, and, from this line count the number of successive "tint of passage" fringes. "Tint of passage" is defined as a sharp isochromatic line located between red and blue isochromatics. This method permits strain determinations at any point located on such a fringe. The black fringe corresponds to zero principal strain difference, and its order p is zero. The first "tint of passage" (fringe order $p = 1$) corresponds to a principal strain difference, f, whose value in microinches per inch is calibrated according to type and thickness of the plastic used. The second "tint of passage" ($p = 2$) corresponds to a strain $2f$; the third to $3f$; the p^{th} to pf, etc.

3. Use an "optical compensator" calibrated in terms of strains. Compensators are used if the number of isochromatics (tints of passage) is insufficient, or if stresses are to be determined at a point outside a fringe. These are devices which artificially produce a tint of passage fringe at any given point of the birefringent plastic for any value of strain.

4. Convert colors into photoelectric currents, and measure these by means of calibrated photometers.

As can be seen from eq 2, the thicker the plastic the more fringes (value of δ) per unit stress will be seen in the plastic. There might, therefore, be a tendency to coat the part with as thick a plastic as possible. However, from a practical point of view, it is never necessary to use coatings more than 0.120 in. thick, since this thickness will provide a strain sensitivity of ± 10 microinch/inch (± 100 psi in aluminum) when a compensator is used to determine the fringe value. The accuracy of strain determination (see eq 3) will depend not only on the accuracy of the measurement of δ (fringe value), but also on the accuracy of the measurement of thickness, t, of the coating. This thickness is known to within a few percent if flat or contoured sheets of plastic are bonded to the part. In case the part is coated with a liquid plastic which is polymerized directly on the surface of the part, the thickness must be measured. The thickness can vary from one point to another, but must be known at any point if precise quantitative analysis is required. The measurement of t can be done with any commercial gage or with a small field meter.[7] The isoclinics giving the directions of ϵ_1 and ϵ_2 are independent of the thickness of the plastic.

The photoelastic coating can be applied by brushing a liquid plastic on the surface of the metal and polymerizing it by applying heat to the part. Alternatively, a prefabricated flat or contoured sheet of plastic[13] can be bonded to the part at room temperature. The maximum strain measured can be of the order of 3 to 50%, depending on the type of plastic used.[7] The 3% elongation plastic (type S) is generally used for metal parts, since it exhibits the highest strain sensitivity. The 50% elongation plastic (type M) is generally used on rubbers. The calibration of plastic is obtained by applying a known strain to a test specimen coated with the plastic to be calibrated. Birefringence (δ) resulting from this strain is measured, and application of the formula $\delta/2t = K(\epsilon_1 - \epsilon_2)$ permits verification of the value of K and the determination of variations of K which might occur as a result of wide temperature changes during test.

Regarding instruments used for the stress or strain analysis, a microscope-type polariscope (small field meter) can be used for very small parts or for investigation of high stress gradients. A large field polariscope can be used for observations and measurements on large parts. They provide the directions of principal strains to within ± 2 deg and the magnitudes of strains to within ± 10 microinch/inch if plastic type S having a K-factor of 0.1 and a thickness of 0.120 in. is used as a coating. Higher sensitivities can be obtained using photocell systems which convert variations of colors into variations of electrical signals. Dynamic measurements and recordings can be performed with high speed cameras, strobe lights or photocells adapted to the instruments.

From the preceding description, it can be seen that this technique is basically different from conventional photoelasticity in that the stress analyst bonds a transparent plastic to the actual part and determines the stresses in the coated part under actual loading conditions—in lieu of making a transparent plastic model and determining stresses in this model under a simulated load. It differs also from the strain gage technique in that strains are quantitatively determined not only in the areas where strain gages are located, but in a continuous manner *at every point* of the surface coated with the photoelastic plastic.

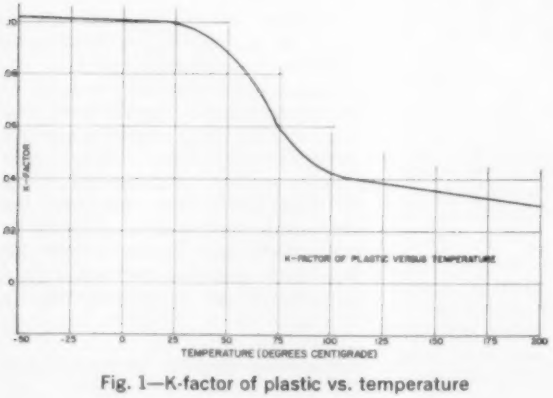

Fig. 1—K-factor of plastic vs. temperature

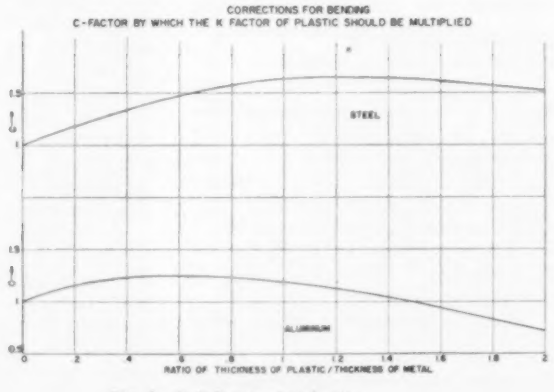
CORRECTIONS FOR BENDING
C-FACTOR BY WHICH THE K FACTOR OF PLASTIC SHOULD BE MULTIPLIED
STEEL
ALUMINUM
RATIO OF THICKNESS OF PLASTIC/THICKNESS OF METAL

Fig. 2—Reinforcement factor

Advantages and Limitations of the Technique

Advantages. The main advantage of the photoelastic-coating technique is that the coating behaves as an infinite number of strain gages with virtually zero gage length distributed continuously over the entire surface of the part to be stress analyzed. The ability to observe strain patterns directly on a loaded part provides a quick and simple means to evaluate the stress behavior of a structure. Since photoelastic plastic, whether in liquid or sheet form, adheres well to the test part, stress analysis can be performed on practically all construction materials (such as metals, concrete,[11] wood, glass and rubber). Photoelastic materials used for the coatings can withstand considerable elongation. Since their birefringence is directly proportional to strain, quantitative measurements are possible in both the elastic and the plastic ranges of deformation of the structural part, and nearly up to the rupture point of most construction materials. On the other hand, very low strains can be measured with compensators in conjunction with reflection-type polariscopes, yielding strains within ±10 microinch/inch (100 psi in aluminum) for type S plastic of 0.120-in. thickness and ±70 microinch/inch for M type plastic of the same thickness.

Photography (still, color, movie and high-speed), black and white or color television, as well as strobe lights and photocell systems, can be used for static or dynamic loading conditions. One reading with light going through the plastic under normal incidence provides the distribution of the maximum shear stresses in the surface of the part. An additional reading, with light going through the plastic under oblique incidence, provides two separate values of principal stresses and their signs. The directions of principal stresses can be known within ±2 deg. The information given at every point is therefore equivalent to a strain-gage rosette, with the advantage that it is continuous over the whole part.

Microscope devices can be incorporated in the compensator polariscopes to provide the information desired in very small parts or even in crystalline grains. If the part is very large, instruments with a large field of illumination will give the over-all strain pattern. If remote measurements must be made, the polarizing illuminators can be placed near the part and an analyzing telescope can be used for measurements over very large distances. Limiting factors are the telescope's power of magnification and the ratio between external light and polarized light illuminating the part.

Systematic measurements over a 4-yr period have proved that the sensitivity of the plastic remains constant and is independent of humidity conditions (even if the part is immersed in water or oil). The sensitivity of the plastic is practically constant within a temperature range of −40 to +95° F. Insensitivity to atmospheric conditions makes it possible to use the photoelastic-coating technique for long-term measurements of structures, such as dams, bridges,

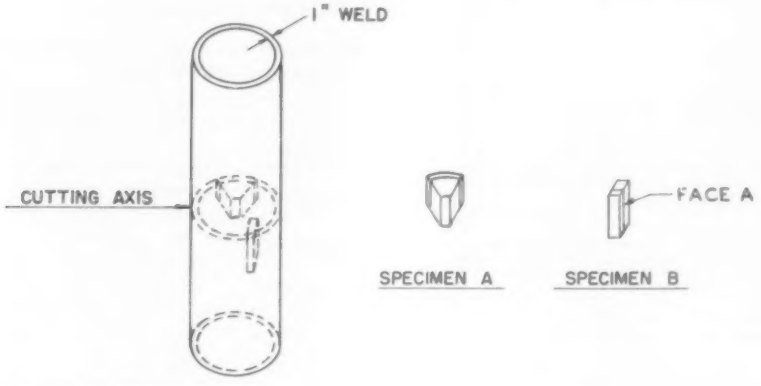

Fig. 3—Shaft weldment

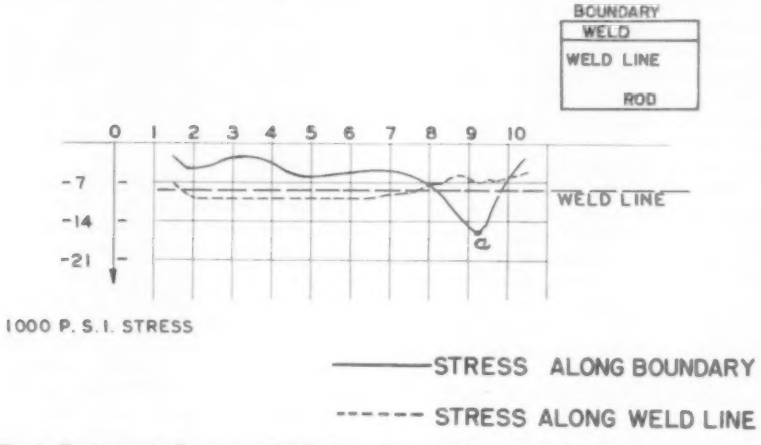

Fig. 4—Test sample B—stress distribution after partial removal of weld

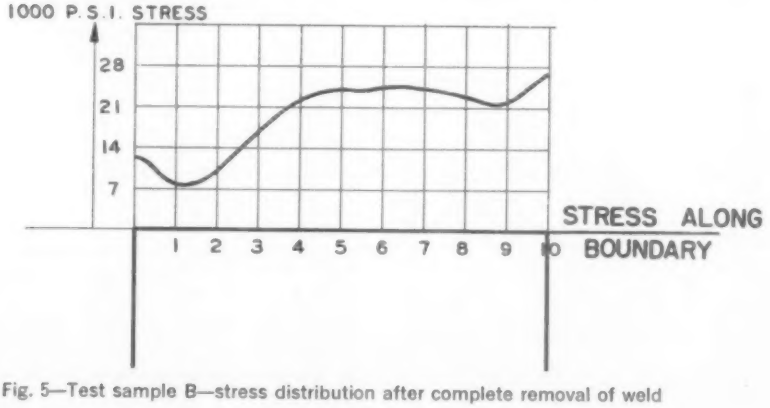

Fig. 5—Test sample B—stress distribution after complete removal of weld

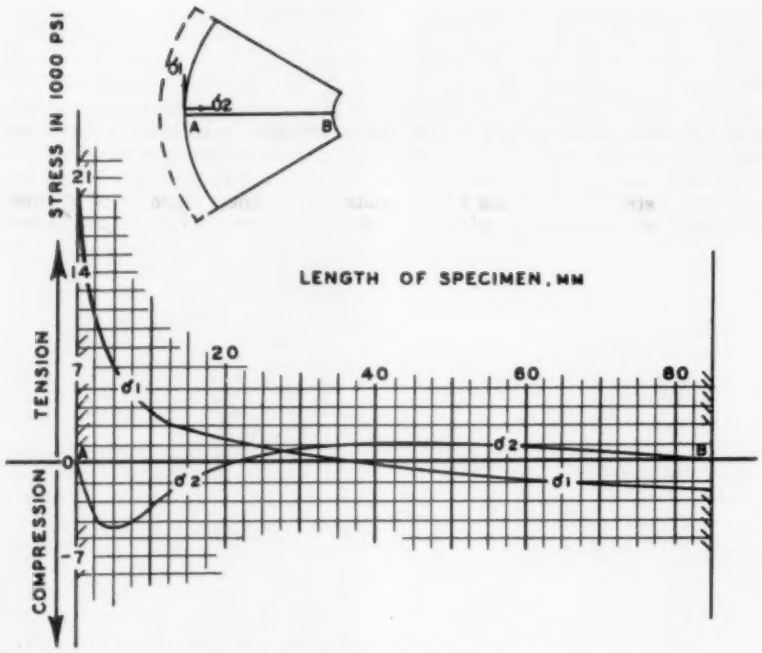

Fig. 6—Gradients of internal stresses in one section of cylinder

etc., and provides a permanent safety device, readable without the use of complicated electronic instrumentation.

Limitations. Stresses cannot be measured in areas of an assembly which cannot be illuminated. Residual strains, however, can be measured if a component part, stressed beyond the elastic limit, becomes accessible to light after dismantling.

The strain-optical constant K varies for temperatures outside the range of -40 to $+95°$ F. Corrections should be made for such temperatures (see Fig. 1).

A wide temperature variation during a test may result in a parasitic birefringence caused by the difference in expansion between the workpiece and the plastic. In this case, it is often necessary to take a measurement of the birefringence before and after loading, to cancel out a possible zero shift in the measurement.

The photoelastic-coating method measures only surface strains. Classical photoelasticity, using the "freezing" technique,[8, 9, 12] provides the strain distribution inside of transparent plastic models as well as on the surface.

Figure 2 shows how to correct the value of K-factor in case of thin parts coated with thick photoelastic plastic subjected to bending loads to account for reinforcement and related effects.[14] In case parts are subjected to pure tensile loads or any two-dimensional stress system, the correction factor can be computed from the following formula:[14]

$$\left(1 + \frac{S_p E_p}{S_m E_m}\right)$$

where:

S_p = cross-sectional area of the plastic

S_m = cross-sectional area of metal

E_p and E_m = modulus of elasticity of plastic and of metal

When very thin coatings must be used, the accuracy of birefringence readings will be poor for low strain levels.

Part II. Application of the Photoelastic-coating Technique to Welded Structures

Photoelastic Measurements of Residual Stresses Caused by Welding

The measurement of residual stresses is done mostly by relaxation methods. A portion of the part in which the residual stresses must be measured is removed by machining or drilling holes or by other procedures, so that the stresses which existed in the removed metal are transferred to the remaining portion of metal and then measured. The measurements can be made either by determining the dimensional changes of the part, or directly by strain measurements. Of course, the strain measuring device (in this case the photoelastic coating) is attached to the part prior to stress relaxation.

The method of welding for each case treated here is not described, since it is outside the scope of the paper. Only the different stress distributions caused by welding are discussed.

CASE NO. 1. *Measurements of Residual Stresses in a Mild-steel Rod, Protected with a Heavy Stainless-steel Weld on Its Entire External Surface.* The rod of mild steel, 4 ft in diam, was protected by a deposit of stainless-steel weld, approximately one inch thick, on its entire external surface. During welding, internal stresses developed in the weld as well as in the rod. Several sections were subsequently cut out of the rod. This description concerns two such sections, one longitudinal and one transverse, as shown in Fig. 3. Sheets of type S plastic,

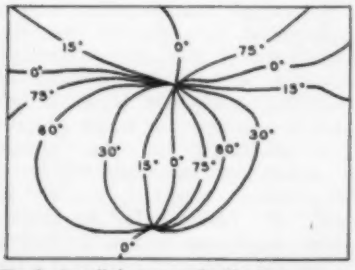

Fig. 7—Isoclinic curves for the transverse section (specimen A) after complete removal of weld

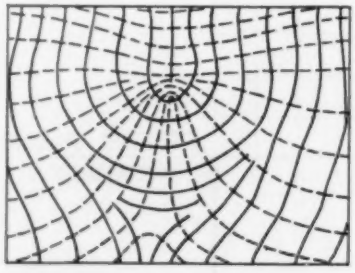

Fig. 8—Isostatics, or stress trajectories, derived from isoclinic curves of Fig. 7.

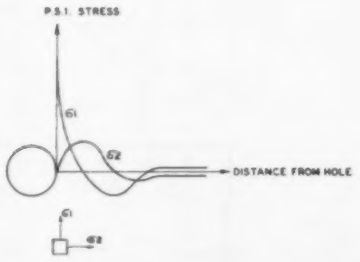

Fig. 9—Stress relaxation caused by a drilled hole

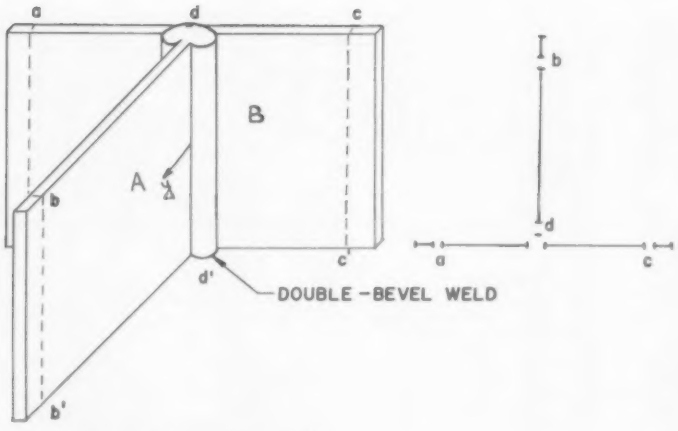

Fig. 10—Plate-weldment test sample

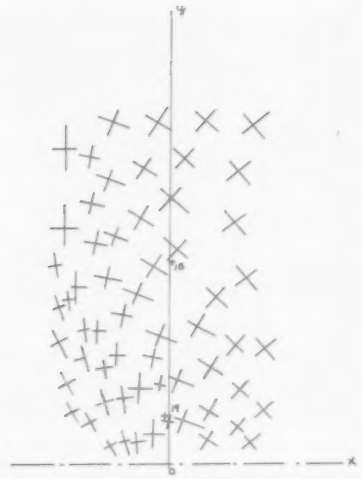

Fig. 11—Directions of internal principal stresses in plate A

.120-in. thick, were bonded to specimen A and B (Fig. 3).

Weld material was machined off in shallow cuts to relieve the stresses due to welding. The strain distribution was measured after each 0.040 in. of material was removed, until the weld was completely removed. Magnitudes of principal strains were measured with small field and oblique-incidence meters. The directions of principal strains were determined with a large field meter. The results are represented in Fig. 4 through 8.

Figure 4 shows the variation of $\sigma_1 - \sigma_2$ along the boundary of the longitudinal section (see Fig. 3, specimen B, Face A), and along the weld line. The amount of weld removed was $^1/_4$ in. The peak of the curve (a) corresponds exactly to the region where there was an interruption of the continuous weld.

Figure 5 represents the stress variation along the boundary of the longitudinal section after the weld had been completely removed.

Figure 6 shows the stress distribution (σ_1 and σ_2) along line A-B of the transverse section (specimen A), after the weld had been completely removed.

Figure 7 shows the isoclinic curves for transverse splices, and Figure 8 shows the isostatics (stress trajectories) drawn from the isoclinic pattern.

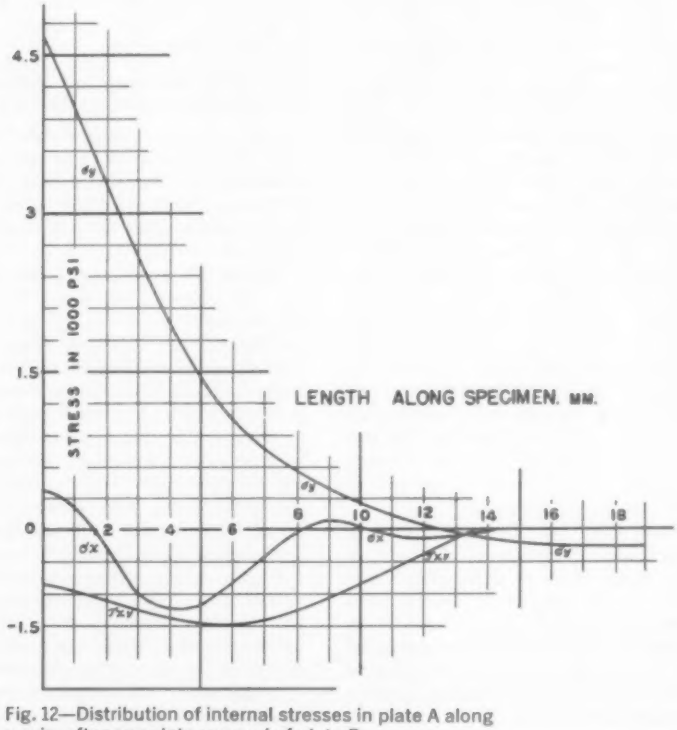

Fig. 12—Distribution of internal stresses in plate A along y axis, after complete removal of plate B

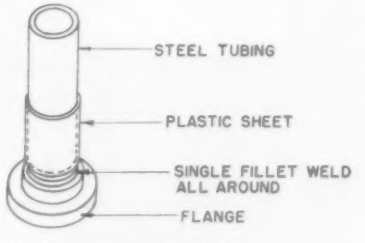

Fig. 13—Flange weldment

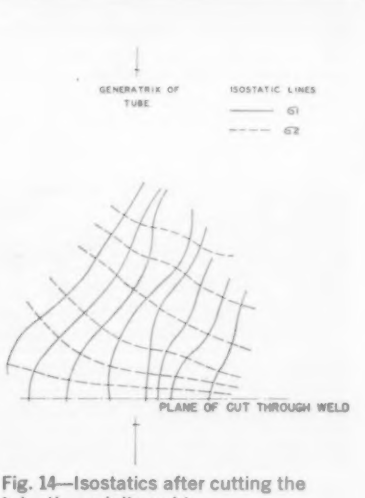

Fig. 14—Isostatics after cutting the tube through its weld

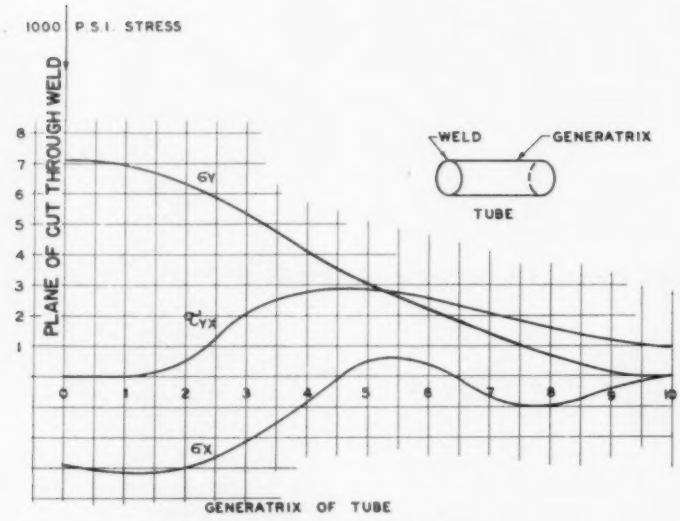

Fig. 15—Stress distribution along generatrix of tube

αk	TYPE OF SPACING OF SPOT WELDS	TYPE NO.
3.22		1
2.37		2
2.34		3

Fig. 19—Stress-concentration factors

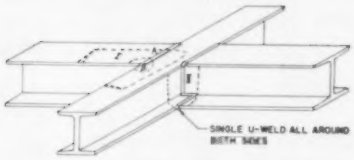

Fig. 20—I-beam weldment

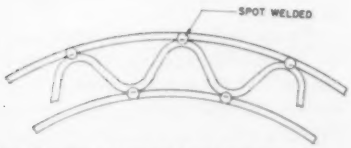

Fig. 16—Sheet metal spot weldment

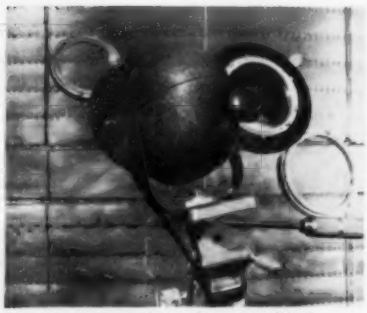

Fig. 17—Partial view of spot-welded pressure vessel and large field meter

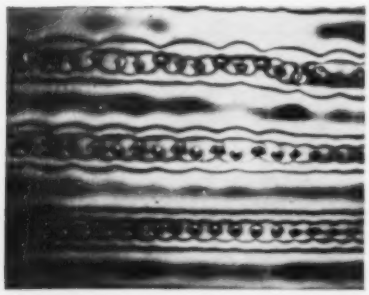

Fig. 18—Isochromatic fringe pattern around 3 lines of spot welds

Another test was performed on another transverse section cut from the same rod. In this case, internal stresses were measured by drilling holes in the weld and in the rod itself and then measuring the stresses relaxed after drilling. The plastic used was the same as before. Figure 9 shows a typical stress record along a line perpendicular to such a drilled hole.

CASE NO. 2. *Residual Stresses in Two Aluminum Plates Welded at Right Angles.* Two aluminum plates of 0.25-in. thickness were welded at right angles. Sheets of photoelastic plastic type S of 0.076-in. thickness were bonded to the plates. Figure 10 shows the different cuts made in the plates to relieve, first the stresses due to manufacturing the plates and then, the stresses due to the weld. All measurements were made with a large field meter for the directions and the difference of principal stresses, and with an oblique-incidence meter for the separate values of principal stresses.

Figures 11 and 12 show, respectively, the directions of principal stresses in different points of the plate and values of principal stresses in plate A after cutting the plates along *dd'*.

CASE NO. 3. *Residual Stresses in a Tube Welded to a Flange.* A steel tube of $d_o = 3$ in. and $d_i = 2$ in., 12 in. long, was welded to a flange (Fig. 13.) The plastic was applied by the contoured-sheet technique, which consists of molding a sheet of plastic and bonding it to the part while the plastic is only partially polymerized (45 min curing in the mold at 125° F). At this stage the sheet is pliable and will fit almost any curvature. It is bonded to the part in its partially polymerized state. Full polymerization is achieved within a 24-hr cure period at room temperature. The cement will also harden during this period, and the test can be performed.[13] The instruments used for analysis were the large field meter, the small field meter and the oblique-incidence meter.

The stress relaxation was achieved by making a cut through the weld to separate the flange from the tube. Figure 14 shows the variation of the directions of the principal stresses on the surface of the tube, and Fig. 15 gives the magnitudes of the stresses, σ_x, σ_y and τ_{xy}, along a longitudinal axis.

Photoelastic Measurements on Welded Structures Subjected to External Loads

CASE NO. 1. *Spot-welded Pressure Vessel.* The wall of the vessel consisted of two stainless-steel envelopes reinforced with a corrugated sheet spot-welded to the envelopes (Fig. 16).

Loading was produced by applying oil pressure between the two envelopes.

The surface of the vessel was coated with a 0.040-in. thick contoured sheet of plastic type A. A large field and a small field meter were used for strain measurements. Since the thickness of the plastic was comparable to the thickness of the envelopes, corrections of *K*-factor of plastic were applied in accordance with Fig. 2.

Figure 17 shows a portion of this vessel and large field meter used for strain measurements. Figure 18 shows the fringe pattern along different types of spot-weld configurations. The stress concentration factors (αk) were found for three types of spot-weld spacings

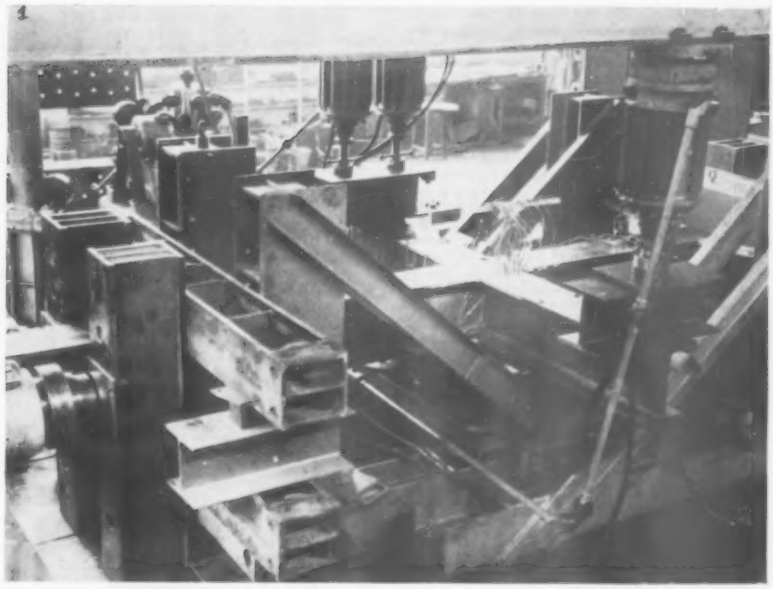

Fig. 21—Over-all view of test setup for cross-welded I-beams subjected to bending

(see Fig. 19); αk is defined as the absolute value of maximum shear stress around the spot weld divided by the absolute value of maximum shear stress developed between two rows of spot welds. Obviously Configurations 2 and 3 (Fig. 19) are superior to Configuration 1.

CASE NO. 2. *Arc-welded Bridge-assembly Structure.* The assembly consisted of an arc-welded bridge structure made of two 16-in. mild-steel I-beams welded at right angles to each other, as shown in Fig. 20. A bending load was applied with two hydraulic jacks on the ends of one I-beam, the two ends of the other I-beam being fixed in the loading frame shown in Fig. 21. Nine 10- × 10-in. sheets of type S plastic in 0.120-in. thickness were bonded to area "I" of the I-beams, and several contoured sheets of plastic were bonded to area "II" (see Fig. 20).

A large field meter and an oblique incidence meter were used for measurements. Several strain-gage rosettes were also installed to obtain strain data by a second independent method.

Localized yielding occurred around weld A for a load only 20% of the calculated service load, showing that internal stresses caused by welding, superimposed upon small working stresses, resulted in premature yielding. Figures 22 and 23 show the strain patterns around yielded areas. Figure 24 shows the elasto-plastic strain distribution in an area of junction between the two I-beams, as computed from the fringe pattern of Fig. 22.

Conclusion

The basic principles and several test procedures of the photoelastic-coating technique have been presented. Several applications are described to indicate the use of the photoelastic-coating technique in welded structures. Photoelastic-coating techniques can be applied to determine residual stresses and to determine stresses caused by external loading in welded structures. Some of the results presented could have been obtained by other techniques, such as strain gages. However, the photoelastic-coating method is considered superior for many applications, especially where a large area must be surveyed to locate and measure critical strains. The method gives an engineer a quick and thorough understanding of the stress behavior of a structure he is studying. The fact that valid quantitative data can be obtained and the strain distribution observed directly on the working part is obviously one of the most attractive features of this method of strain measurements.

Acknowledgments

The author would like to express his appreciation to Dr. Golubovic of Bufra Co. (Paris, France), to Mr. Hebrant of C.E.C.M. (Brussels, Belgium), to The Budd Co. (Philadelphia, Pa.) and to several others who made available for publication a considerable portion of the information contained in this paper.

Fig. 22—Fringe pattern in area B of I-beams

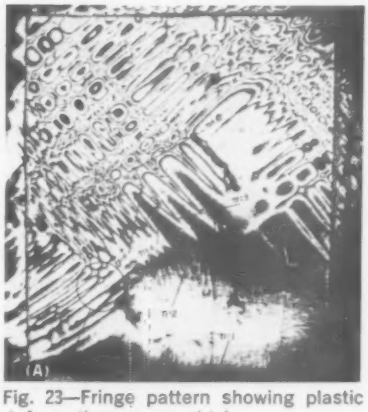

Fig. 23—Fringe pattern showing plastic deformations near weld A

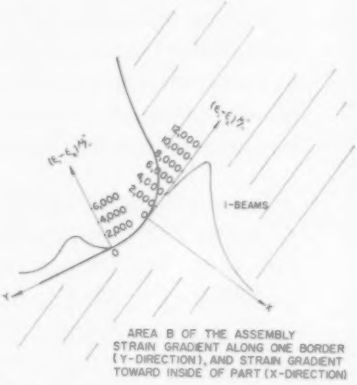
I-BEAMS
AREA B OF THE ASSEMBLY
STRAIN GRADIENT ALONG ONE BORDER (Y-DIRECTION), AND STRAIN GRADIENT TOWARD INSIDE OF PART (X-DIRECTION)

Fig. 24—Strain gradients in area B

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List of Symbols Used

E	= modulus of elasticity
μ	= Poisson's ratio
t	= thickness of plastic
W or m	= workpiece
pc or p	= plastic coating
δ	= relative retardation of light wave or fringe value
δ_n	= relative retardation of light wave or fringe value measured under normal incidence
δ_{ob}	= relative retardation of light wave or fringe value measured under oblique incidence
ϵ_1 and ϵ_2	= principal strains
σ_1 and σ_2	= principal stresses
θ	= angle of incidence of light in plastic
C	= stress optical constant of the plastic
K	= dimensionless constant representing the optical strain sensitivity of the plastic (K-factor);

$$K = (CE/1 + \mu)_p$$

University Welding Research Directory

The Welding Research Council (WRC) was established by interested Engineering Societies and Trade Associations to accomplish certain objectives. These objectives simply stated are: (1) to conduct needed cooperative research in welding and closely allied fields; (2) to disseminate research information; (3) to promote welding research in the universities and (4) to provide a means for cooperation, interchange of ideas and information with similar agencies abroad. One of the several committees of WRC is the University Research Committee.

One of the principal objectives of the University Research Committee is to stimulate research in welding and closely allied fields in the various universities of the United States. The Council has found from past experience, that the research dollar goes further in the university research laboratories than in other laboratories. Moreover, the by-product of the training and education of young men and professors in the various sciences related to welding engineering might be more important in the long run than the solution of specific problems. In recent years, Industry has been particularly appreciative of these specially trained young engineers and scientists.

To assist Industry in making contacts directly with Universities and in placing specific research problems in the Universities for solution, the WRC has compiled this University Welding Research Directory. This Directory describes the facilities and staff available at each of the Universities participating in Welding Research Council projects. It describes each department engaged in welding research, giving in detail the University's research facilities and operations, list of the research officers of the University and staff members, along with classification of typical research projects previously carried out or now underway. Copies of the University Welding Research Directory may be obtained from the Welding Research Council, 29 West 39th Street, New York 18, N. Y. Each company desiring to sponsor research is urged to make direct contacts with the Universities. The Welding Research Council, however, will be glad to assist at all times as far as possible.

Time-Temperature Parameters Affecting Corrosion of 18Cr-8Ni Weld Metals

Long times at low temperatures (800–1100° F) are found to sensitize 18-8 weld metal much more severely than the conventional sensitizing heat treatment of 1200° F for 1 or 2 hours

BY THOMAS J. MOORE

Thomas J. Moore is Assistant Director of Research, Arcos Corp., Philadelphia, Pa.

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Presented on behalf of the Advisory Subcommittee on the Welding of Stainless Steel, High Alloys Committee, Welding Research Council. Chairman: R. B. Gunia. Members: W. O. Binder, H. C. Campbell, F. W. Davis, W. B. DeLong, C. R. Mayne, M. A. Scheil, R. D. Thomas, Jr., R. D. Wylie and T. J. Moore, Secretary. Work performed under AEC Contract No. AT(30-1)-1233.

ABSTRACT. Boiling nitric acid corrosion tests were conducted on 0.026, 0.036, 0.047 and 0.067% carbon 18Cr–8Ni weld metals which were deposited using covered electrodes. All-weld-metal specimens were aged at 800 to 1300° F for 0.1 to 10,000 hr prior to corrosion testing. It was found that the time-temperature-corrosion rate relationship follows a definite pattern which can be presented in the form of a three-dimensional drawing, or as a "contour map" time-temperature-sensitization diagram. Long times at low temperatures (800–1100° F) were found to sensitize the weld metals to a marked degree, much more severely than conventional sensitizing heat treatments of 1200° F for 1 or 2 hr. In general, the corrosion rate was found to decrease with decreasing carbon content, although even the 0.026% carbon weld metal exhibited severe sensitization after low temperature (800–1100° F) ag-

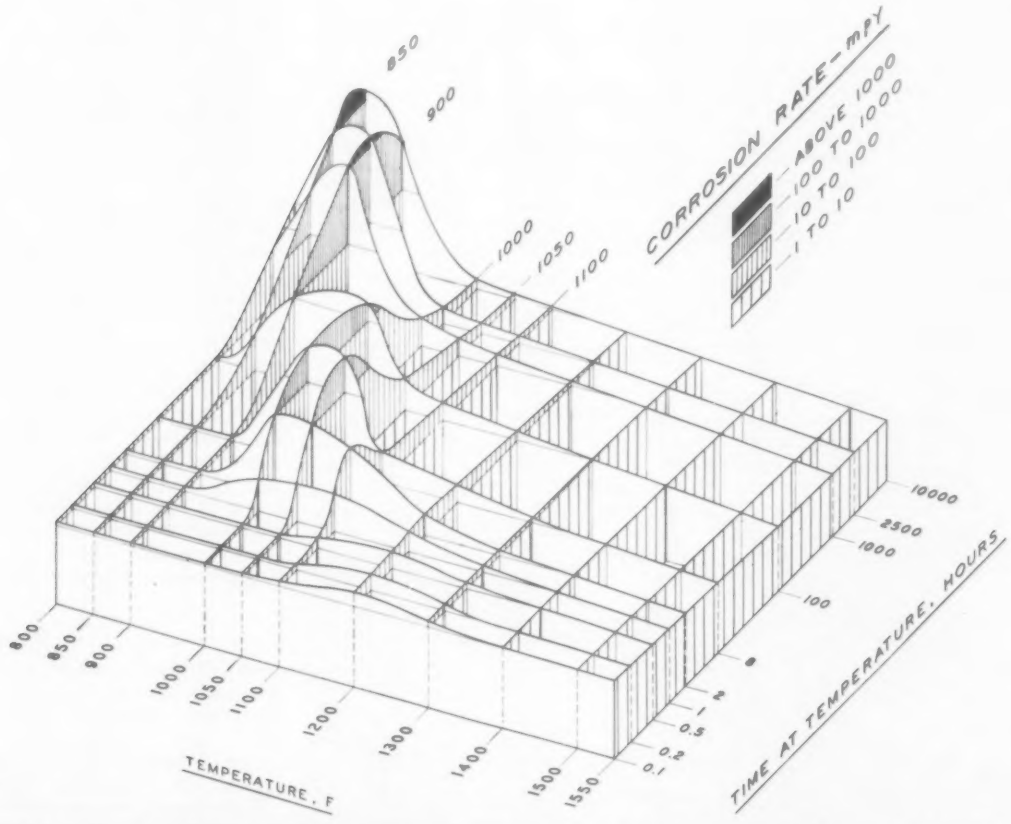

Fig. 1—Three-dimensional drawing illustrating the time-temperature-sensitization relationship for 0.036% carbon 18–8 weld metal which was aged in the as-welded condition prior to corrosion testing (vertical scale is logarithmic, same base as time scale)

Table 1—Chemical Analyses of Weld Metals

Electrode diameter, in.	C	Mn	Si	S	P	Cr	Ni	N	Calculated % ferrite
1/4	0.026	1.20	0.44	0.013	0.021	19.70	10.88	0.070	5
5/32	0.036	0.68	0.33	0.011	0.016	18.51	10.63	0.048	3
5/32	0.047	0.73	0.33	0.015	0.015	18.77	10.84	0.050	2
5/32	0.067	0.62	0.35	0.016	0.006	19.45	10.50	0.040	4

ing. A stabilizing heat treatment of 1200° F for 12 hr prior to 1000° F aging showed promise in maintaining acceptable corrosion resistance for the 0.036% carbon weld metal. However, stabilizing heat treatments prior to 800°–900° F aging did not appear to be effective in reducing the excessive corrosion rates after long-time aging periods.

Introduction

The results of nitric acid and copper-sulfate sulfuric acid tests of a standard partially ferritic Type 347 covered-electrode weld deposit were compared by Poole[11] with four modified Type 347 and one Type 308L weld-metal compositions. In general, the Type 308L weld deposit containing 0.036% carbon possessed the best corrosion resistance of all the compositions tested. In view of the excellent corrosion results obtained with the Type 308L covered electrodes, additional test work was undertaken to measure nitric acid corrosion properties after various aging heat treatments. The effect of carbon content was also investigated for three other 18Cr-8Ni weld metal compositions. Several stabilizing heat treatments were employed prior to subjecting the welds to the aging temperatures in an attempt to reduce the corrosive attack after long times at low temperatures (800–1100° F).

Throughout this paper, since Types 308 and 308L electrodes were studied, the weld metals will be referred to as "18-8" compositions even though the chromium content varied from 18.5 to 19.7% and the nickel from 10.5 to 10.9%.

Test Procedure

All-weld-metal specimens approximately 3/16 x 3/8 x 2 in. were machined longitudinally from the center

Table 2—Boiling Nitric-acid Corrosion Data for 18 Cr – 8Ni Weld Metal Aged in the As-welded Condition—Penetration in Mils Per Year (Average of Five 48-Hr Periods)

	Hours at temperature[a]												
Carbon %	.1	.2	.5	1	2	3	8	30	100	300	500	1000	2000	10,000
800° F aging														
0.036	..	..	..	11	10	..	10	...	11	..	...	48	...	...
900° F aging														
0.026	..	..	..	6	7	..	6	...	13	..	38	41	29	262
0.036	..	..	..	11	11	..	10	...	108	..	777	1043	1302	435
0.047	..	..	..	22	50	..	94	..	484	..	...	...	...	...
0.067	..	..	..	84	160	..	226	...	642	..	...	...	...	...
1000° F aging														
0.026	..	..	..	6	6	..	20	383	136	16	...	12	...	...
0.036	..	..	..	26	106	..	264	...	540	..	...	22	...	...
0.047	..	..	..	49	101	..	290	...	435	..	...	...	...	...
1050° F aging														
0.026	..	..	..	6	7	..	43	...	17	..	...	...	...	...
0.036	..	..	..	19	104	..	288	...	25	..	...	16	...	...
0.047	..	..	..	101	278	..	306	...	156	..	...	...	...	...
0.067	..	..	..	235	373	..	543	...	272	..	...	...	...	...
1100° F aging														
0.026	..	..	..	12	11	14	23	...	11	..	...	...	..	...
0.036	12	..	34	31	72	..	24	...	12	..	...	...	...	
0.047	..	..	..	116	206	..	61	...	38	..	...	...	...	...
1200° F aging														
0.026	..	..	..	11	10	..	10	...	8	..	...	...	...	...
0.036	17	16	17	18	19	..	16	...	16	..	...	12	...	...
0.047	..	..	..	18	24	..	16	...	16	..	...	...	...	...
0.067	..	..	..	48	41	..	36	...	20	..	...	...	...	...
1300° F aging														
0.036	13	12	13	13	12	..	11	...	11	..	...	...	...	...
1550° F aging														
0.036	..	..	..	...	...	..	8[b]	...	7[b]	..	...	...	...	...
1700° F aging														
0.036	..	..	..	...	...	..	6[b]	...	6[b]	..	...	...	...	...
1950° F aging														
0.036	..	..	..	...	6[b]	..	...	...	...	..	...	...	...	...

[a] Water quenched after aging.
[b] Data from U. S. AEC Report NYO-3499 (see Bibliography).

of stainless-steel butt weldments in such a manner that the $^3/_8$-in. dimension was in the direction of the plate thickness. For the covered 18-8 electrodes containing 0.026, 0.036 and 0.047% carbon, Type 304L stainless-steel plate and backing strip were employed, and for the 0.067% carbon electrodes the base material was Type 304. The $^1/_2$-in. thick plates were clamped securely to the work bench prior to welding to prevent distortion. The root spacing was $^1/_4$-in. and the included angle of the welding groove was 60 deg. Welding procedures were in accordance with the AWS-ASTM A298-55T specification for E308-15 or E308L-15 electrodes.

All-weld-metal blanks were aged at temperatures ranging from 800 to 1300° F for periods of 0.1 to 10,000 hr. Heat treatments for less than one hour were accomplished in a salt bath. The remaining heat treatments were accomplished by placing the specimens in a furnace which was already at temperature, holding for the specified time, and water quenching.

After the aging heat treatments, the specimens were subjected to the boiling nitric-acid corrosion test in accordance with ASTM A262-55T standards. All specimens were tested for five 48-hr periods. Single flasks were employed for each specimen since it has often been cited that two specimens of varying corrosion rates should not be tested in a single flask. The chromium ion corrosion product has been found to accelerate the corrosion rate.[3]

It has been reported[5, 12] that the nitric-acid solution will attack not only grain boundaries in which carbides are precipitated but also those having sigma-phase precipitation. For this reason, the nitric-acid test will reveal susceptibility to intergranular corrosion whether the cause is chromium-carbide precipitation or sigma precipitation. The boiling nitric-acid corrosion tests which were employed in this investigation are designed to give quantitative data on the effect of aging heat treatments on intergranular corrosion resistance and are not intended to duplicate service applications.

Test Results

Chemical analyses of the 18-8 weld metals were obtained following the AWS-ASTM A298-55T procedures and are presented in Table 1. On the basis of the Schaeffler diagram, the ferrite content of the as-deposited welds ranged from 2 to 5%.

The heat-treating schedule and the corrosion-test data are presented in Table 2. Presentation of the test results (for 0.036% carbon weld metal) in the form of a three-dimensional drawing is given as Fig. 1.

In Fig. 1, it will be observed that (1) as the aging temperature decreases, the peak corrosion rate increases; (2) the peak value manifests itself in successively longer periods of time with decreasing temperature. The peak corrosion rates are below the arbitrarily acceptable value of 24 mils per year for aging temperatures of 1200° F or above, but, at aging temperatures below 1200° F, the peak corrosion rates far exceed acceptable values. This phenomenon is illustrated in another manner in Fig. 2. These results confirm the findings of Ebling and Scheil[4] that low-carbon Type 308 weld deposits are adversely affected by low-temperature (1000–1100° F) stress-relief heat treatments, and also by 1000-hr aging heat treatment at 900° F.

Figure 3 is a time-temperature-sensitization diagram for the 0.036% carbon 18-8 weld metal. The dashed lines indicate that no data are available to construct certain portions of the curve. Ebling and Scheil[5,6] have recently presented graphs of this type for Types 347, 304L and 316L wrought material and referred to them as TTS diagrams. Figure 3 was prepared by taking the time-temperature relationship at particular corrosion-rate levels and plotting a graph showing the contours at various corrosion levels as a function of time and temperature. From this diagram, the degree of intergranular attack can be estimated assuming that the time-temperature relationships are known. Required cooling rates from annealing temperatures for specified maximum rates of corrosive attack may be approximated with the aid of this diagram.

The effect of carbon content on the corrosion resistance of 18–8 welds after aging at various temperatures is shown graphically in Fig. 4. At each aging temperature, the curves of corrosion rate vs. time-at-temperature are displaced to higher levels as the carbon content increases. On the basis of these data, it appears generally that corrosion rates are affected by carbon content and that it is desirable to maintain the carbon as low as possible if intergranular corrosive attack is anticipated. On the other hand, it appears that the peak corrosion rates at the lower temperatures of 900 and 1000° F are not significantly reduced by lowering the carbon content.

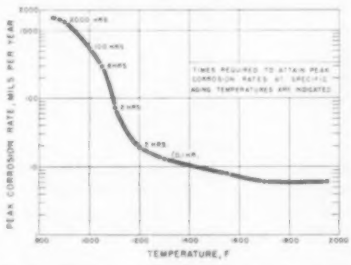

Fig. 2—Peak corrosion rate vs. aging temperature for 0.036% carbon 18–8 weld metal which was aged in the as-welded condition

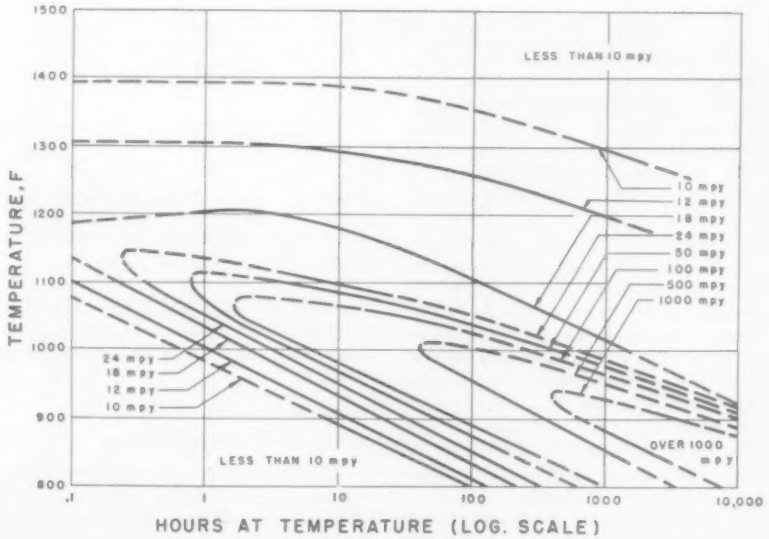

Fig. 3—Time-temperature-sensitization diagram for 0.036% carbon 18–8 weld metal which was aged in the as-welded condition

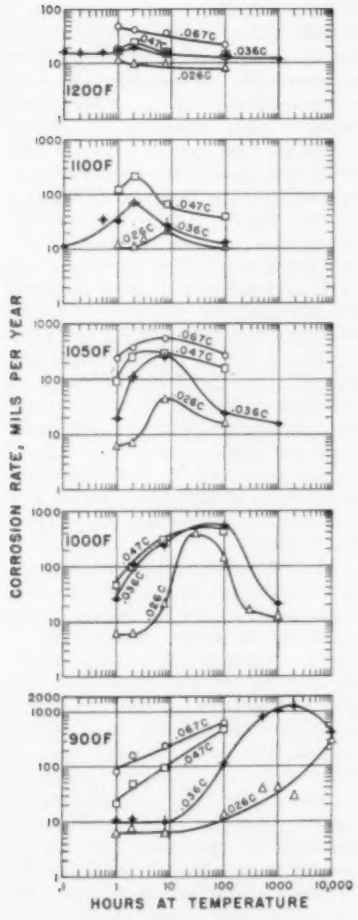

Fig. 4—Corrosion rate vs. time-at-temperature curves illustrating the effects of carbon level and aging time on the corrosion resistance of 18–8 weld metals which were aged in the as-welded condition

Table 3—The Effect of Stabilizing Heat Treatments on the Boiling Nitric-acid Corrosion Resistance of 0.036% Carbon 18-8 Weld Metal—Penetration in Mils Per Year (Average of Five 48-hr Periods)

Condition before aging	Hours at temperature[a] 0	1	2	8	100	1000	10,000
As-welded	7[b]	..	...	...	...	...	...
900° F aging							
As-welded[c]	..	11	11	10	108	1043	435
1200° F—12 hr, ac	..	20	17	25	58	80	75
1000° F aging							
As-welded[c]	..	26	106	264	540	22	...
1200° F—8 hr, a.c.	..	..	29	36	24	91	...
1200° F—12 hr, a.c.	..	..	14	16	14	16	...
1300° F—8 hr, a.c.	..	..	17	22	16	44	...

[a] Water quenched from the aging temperature.
[b] Data from U. S. AEC Report NYO-3499 (see Bibliography).
[c] These data also appear in Table 2.

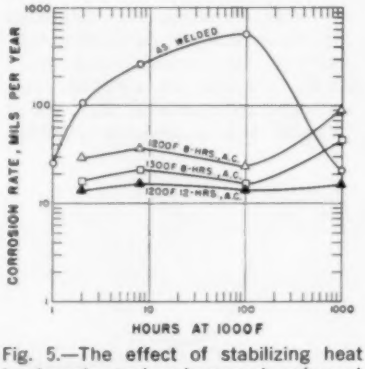

Fig. 5.—The effect of stabilizing heat treatments and subsequent aging at 1000° F on the corrosion resistance of 0.036% carbon 18–8 weld metal

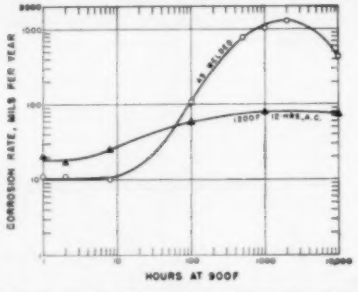

Fig. 6—The effect of a stabilizing heat treatment and subsequent aging at 900° F on the corrosion resistance of 0.036% carbon 18–8 weld metal

An attempt was made to reduce the exceedingly high corrosion rates by heat treatment prior to aging at 900 and 1000° F. In Table 3 the heat-treating schedule is presented with the corrosion-test results for 0.036% carbon 18–8 weld metal. The 1000° F data are graphically illustrated in Fig. 5. After 100 hr, it appears that the corrosion rates have been reduced to an acceptable level by all three stabilizing heat treatments, but after 1000 hr the only specimen which exhibited satisfactory corrosion resistance was the one which was stabilized at 1200° F for 12 hr. The 1200° F 8-hr and the 1300° F 8-hr stabilizing heat treatments appear to be ineffective.

A 1200° F 12-hr stabilizing heat treatment prior to aging at 900° F reduced the peak rate of corrosive attack below that obtained in the as-welded condition (see Fig. 6). Nevertheless, the corrosion rates are still well above acceptable values.

Mechanism of Carbide Precipitation

The mechanism of carbide precipitation was outlined by Bain and Aborn[1] in 1930 for 18–8 stainless-steel wrought materials. Carbon which is in solution at high temperatures is rejected to the grain boundaries at temperatures between 700 and 1500° F, where it combines with chromium to form chromium-rich carbide particles. X-ray diffraction studies[14] of Type 304L steel heated at 1250° F for 2 hr have revealed that the intergranular constituent is the complex carbide: $(Fe, Cr)_{23}C_6$. It follows that the areas immediately adjacent to the carbide particles are reduced substantially in chromium content. Material in this condition is often referred to as being sensitized. Thus, media which would not ordinarily be corrosive might cause severe intergranular attack immediately adjacent to carbide particles. Bain, Aborn and Rutherford[2] pointed out that (1) sensitization is inevitably followed by restoration if enough time is given at constant temperature and (2) maximum sensitivity is a function of carbon content and not a function of either chromium (15–19%), nickel (7.5–11%), nor the sum of the two.

Since the work which is reported in this paper is concerned with 18–8 weld metals containing 2 to 5% ferrite, the mode of carbide precipitation differs slightly from that of the fully austenitic base materials. Chromium carbides are first precipitated along the ferrite-austenite interfaces and then along the austenitic grain boundaries. The inherently larger grain size of the weld metal tends to increase the severity of the intergranular attack because of the reduced grain-boundary area which is available for the precipitation of carbides. A photomicrograph of the 0.036% carbon 18–8 weld metal illustrating the mode of carbide precipitation is shown as Fig. 7.

The severe intergranular nature of the corrosive attack on sensitized 18–8 weld metal which was aged at 900° F for 1000 hr prior to testing

is illustrated in the photomicrograph in Fig. 8. There is no evidence of preferential attack per se on the ferrite islands.* This confirms the findings of others.[7, 12]

Discussion

Diffusion rate D vs. temperature may be expressed by the equation[9]

$$D = Ae^{-Q/RT}$$

where A is a constant, Q is the activation energy for diffusion, R is the gas constant, and T is the absolute temperature. Thus, there will be an exponential increase in D with increasing temperature. At the higher aging temperatures, 1200–1300° F, the intergranular chromium carbides form more rapidly due to the greater diffusion rates of carbon and chromium. At these temperatures the carbide particles, once nucleated, grow very rapidly and tend to agglomerate along the grain boundaries.

Since there is a relatively high diffusion rate for interstitial carbon atoms as compared with chromium atoms, which form a substitutional solid solution, the values of D for the former will be much greater. Thus, at a given temperature, the intragranular carbon atoms rapidly diffuse to the grain boundaries and combine there with chromium atoms to form chromium carbides. Chromium-carbide precipitation will continue until the carbon content of the matrix is below the solubility limit at that temperature. The diffusion of chromium atoms from the grain interior to replenish the chromium-depleted zone is a much slower process. In the interim, the intergranular area is susceptible to corrosive attack.

From nucleation theory,[10] it follows that as the aging temperature is lowered, the size of a stable chromium-carbide nucleus is reduced. Additionally, at lower aging temperatures, the growth rate, which depends on diffusion, is slower. The precipitation phenomenon is accentuated by the fact that the limit of solid solubility of carbides in austenite decreases with temperature. Thus, at the lower aging temperatures (800–1100° F), a more complete envelope of chromium carbide will surround the austenitic grains, although longer aging times are required to produce this condition.

At peak sensitization at 800 to 900° F it is postulated that there exists a continuous network of very small intergranular chromium-carbide particles which are not distinguishable under the optical microscope. It should be realized that the chromium-depleted zone immediately adjacent to the submicroscopic chromium carbides is identical to the zone adjacent to the larger chromium carbides and must be replenished by chromium diffusion from the matrix. Since chromium diffusion at lower temperatures is slower than at elevated temperatures, longer periods of time are required to restore the chromium in the depleted areas.

Ebling and Scheil[5, 6] have presented nitric-acid corrosion data for Types 347, 316L and 304L wrought products similar to the data which have been reported in this paper. They concluded that (1) for Type 347, the corrosion rates resulting from 700 to 1100° F aging can be

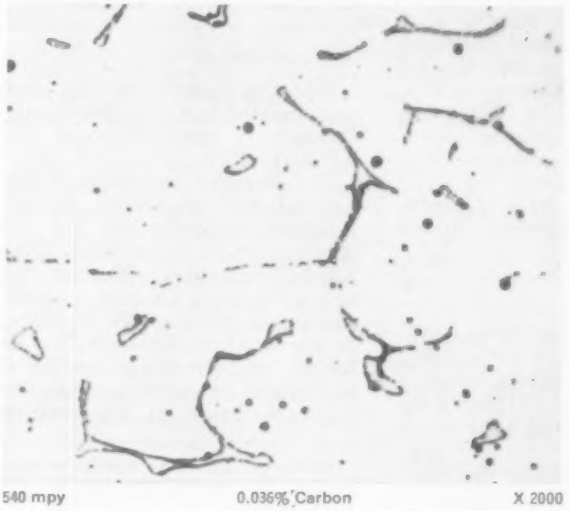

Fig. 7 — Microstructure of 18–8 weld metal which was aged at 1000° F for 100 hr. Notice the carbide precipitation at the ferrite-austenite interfaces and the intergranular carbides along the austenitic grain boundaries (10% chromic acid etch). (Reduced by 25% upon reproduction)

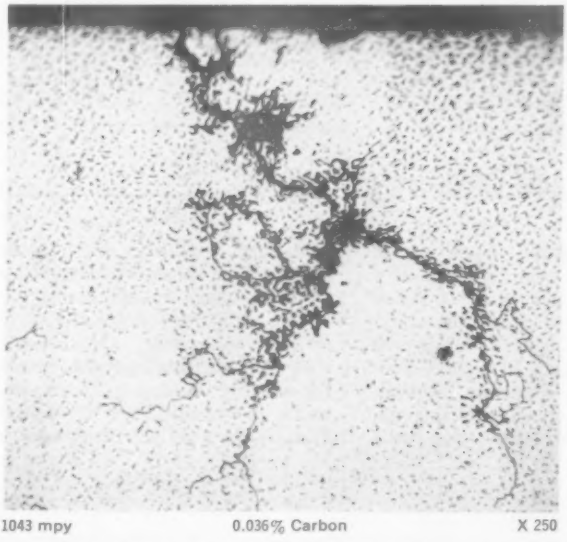

Fig. 8—Photomicrograph of 18–8 weld metal illustrating severe intergranular corrosion on material aged at 900° F for 1000 hr (10% chromic acid etch)

* Since chromium carbides have precipitated at the interface between the dendrites of ferrite and the austenitic matrix in the aged material (in addition to precipitating at the austenitic grain boundaries), there is a tendency for corrosive attack to occur immediately adjacent to these carbide particles, which therefore resembles ferrite attack. This effect is felt to be of secondary importance when compared with the intergranular c rrosion which occurs at the austenitic grain boundaries. In the relatively low ferrite welds under consideration in this program, there is little or no tendency for a continuous network of ferrite islands to exist.

By means of magnetic properties, Schaeffler Diagram calculations, and metallographic procedures, it was found that the ferrite content of the 0.036%-carbon 18-8 weld was 3% in the as-deposited condition and was the same after 1000 hr at 900° F; i.e., this material was structurally stable except for the chromium carbide precipitation. Therefore, it appears clear that the differences in corrosion rate for the as-deposited vs. aged weld metal (7 vs. 1043 mils per year) is not associated with corrosive attack on the dendrites of ferrite.

decreased substantially by pre-aging stabilization at 1650° F for 2 hr; (2) for Types 316L and 304L, heat treatment at 1650° F for 2 hr was ineffective; (3) it is doubtful that a stabilizing heat treatment would have a beneficial effect for Types 316L and 304L materials. Rosenberg and Darr's[12] findings were similar for twenty-three 18-Cr – 10Ni austenitic stainless steels tested after various heat treatments in a boiling acidified copper-sulfate solution.

It should be realized that the exceedingly high corrosion rates which have been reported for Type 308L weld metals are a consequence of 800 to 1100° F aging heat treatments. In the as-welded, stress-relieved [1600° F, 2 hr, air cooled (a.c.)], and sensitized (1200° F, 1 hr, a.c.) conditions, Marshall[8] reported that Type 308L weld metal exhibited low corrosion rates in boiling nitric acid. This is in agreement with the results obtained by Ebling and Scheil[4] and those reported here. Marshall[8] has also reported that Type 304L base material can withstand any normal welding operation without impairment to its corrosion resistance.

Conclusions

1. Longer times at low temperatures (800 to 1100° F) sensitize 18–8 weld metal much more severely than the conventional (1200° F for 1 or 2 hr) sensitizing heat treatment.

2. There is a definite time-temperature-corrosion rate relationship for 18–8 weld metal which lends itself to presentation in the form of a three-dimensional drawing or a "contour map" TTS diagram.

3. A stabilizing heat treatment of 1200° F for 12 hr proved to be effective in inhibiting corrosive attack for 0.036% carbon 18–8 weld metal for aging periods of up to 1000 hr at 1000° F.

4. There does not appear to be a suitable pre-aging stabilizing heat treatment to avoid the extremely high rates of corrosive attack for Types 308 and 308L weld metals which are aged at temperatures of 800 to 900° F.*

5. The desirability of maintaining the carbon content of 18–8 welds at as low a level as possible has been demonstrated, although at temperatures of 800 to 1000° F peak corrosion rates were extremely high, even at 0.026% carbon.

Acknowledgments

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* Work now underway on the effects of various stabilizing heat treatments prior to aging at 850° F for periods up to 20,000 hr indicates that the following stabilizing heat treatments have not proved to be beneficial: 1100° F for 24 hr, a.c.; 1200° F for 15 hr, a.c.; 1300° F for 12 hr., a.c.

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IIW Multilingual Collection of Terms

The International Institute of Welding has recently issued a third part to this valuable series of terms for welding and allied processes in twelve languages (Danish, Dutch, English, Finnish, French, German, Italian, Norwegian, Serbo-Croat, Slovene, Spanish and Swedish). It deals with arc welding. The terms adopted are those established by common usage in each country.

The indexing follows the style of previous parts (which dealt with gas welding, general terms for welding procedure, characteristics and inspection of welds) and allows easy translation of a term or expression from one language to another.

This publication is available from the Association Suisse pour la Technique du Soudage, St. Alganvorstadt 95, Bale, Switzerland, priced as follows—Bulk: Member Societies of IIW, 5.15 Swiss francs. Retail: 7.75 Swiss francs.

Some Observations on the Kinzel and Drop-Weight Tests

WRC-sponsored study is aimed toward a better understanding of the factors which control the results obtained from the Kinzel and drop-weight tests for the measurement of the notch ductility of steels used in welded structures

BY S. A. AGNEW, M. D. MITTELMAN AND R. D. STOUT

Introduction

The problem of brittle fracture has prompted the development of a number of tests for measurement of the notch ductility of steels used in welded structures. Because considerable confusion exists about the relative significance and usefulness of these tests, a series of projects at Lehigh University for the Weldability Committee of WRC has been undertaken to clarify the relations among various testing methods.

The study reported here was aimed toward a better understanding of the factors which control the results obtained from the Kinzel and the drop-weight tests. Hopefully, such information will permit the similarities and differences of the two tests to be clarified. The degree of correlation of the tests can then be established and put to use.

The Kinzel slow-bend test allows measurements to be made at intermediate stages during testing. Its behavior is therefore more readily analyzed than that of the drop-weight test. The variables of testing considered were either mechanical in nature or associated with the conditions of welding. For the Kinzel test, the variables were the loading system, the weld reinforcement, the size of the weld zone and the criterion of failure. For the drop-weight test, they were specimen width, thickness, the weld-metal hardness and the heat-affected zone.

The Kinzel Test

The Kinzel specimen was designed to represent the combination of weld zone and base plate as it appears in a structure in service.[1] The 1% lateral-contraction transition temperature, specified for the test, is controlled by the over-all behavior of this complex specimen. While not expected to predict service performance, it was intended to be an index which responds appropriately to the variables significant to service. It can be used with a given steel for measuring changes in notch toughness produced by changes in welding variables, or with given welding conditions to measure changes in notch toughness produced by changing the steel or its condition. The effect of welding conditions was of primary interest in this study, because variation thereof introduces problems that are not encountered in the evaluation of steels.

The weld zone contributes to failure of the specimen, at and near the transition temperature, by providing a triggering area which initiates cracking. The most brittle area of the weld zone may initiate a cleavage crack at any stage of bending after the onset of yielding; the more notch tough this area, the greater the delay. According to the accepted interpretation of transition temperature, weld zones of greater notch toughness would be expected to lower the transition temperature. On this basis, the effects of welding variables such as heat input per inch, preheat, and postheat may be measured. While the effect of welding on carbon steels revealed by the Kinzel test confirms general experi-

S. A. AGNEW, is Instructor in Metallurgy and R. D. STOUT is Head, Dept. of Metallurgy, Lehigh University, Bethlehem, Pa., and M. D. MITTELMAN is associated with the Kaiser Steel Corp.

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Table 1A—Chemical Analyses of Steels, wt. %

Steel	Grade	Code	C	Mn	P	S	Si	Ni	Cr	Al	Mo
C1035	...	S	0.33	0.69	0.01	0.026	0.22	0.03	0.03	0.005	0.01
ASTM A285	C	AR	0.20	0.49	0.01	0.018	0.04	0.04	0.01	0.007	0.01
ASTM A201	B	EY	0.14	0.51	0.01	0.033	0.20	...	...	...	...
ASTM A212	B	BR	0.32	0.71	0.02	0.021	0.24	0.02	0.03	0.005	0.01
ASTM A203	D	ER	0.17	0.59	0.01	0.026	0.24	3.34	0.06	0.024	0.02
ASTM A302	B	OR	0.21	1.20	0.01	0.028	0.25	0.15	0.07	0.029	0.50
ASTM A302	B	TY	0.19	1.26	0.02	0.025	0.22	...	...	...	0.46
ASTM A387	D	SY	0.09	0.44	0.013	0.011	0.25	...	2.18	...	0.96
ASTM A357	...	OY	0.06	0.50	0.019	0.022	0.34	0.13	4.96	...	0.55
HY-65[a]	...	G	0.12	0.48	0.013	0.032	0.21	2.16	...	...	0.39
HY-80	High	HY	0.15	0.21	0.01	0.015	0.23	2.97	1.85	0.037	0.46
T-1[b]	...	R	0.15	0.93	0.01	0.022	0.27	0.89	0.48	...	0.44

[a] Cu = 0.70.
[b] V = 0.06. B = 0.0031.

Table 1B—Mechanical Properties of Steels

Steel	Condition	0.2% Y.S. ksi	U.T.S., ksi	Elongation in 1 in., %	R.A., %	Charpy V 15 ft/lb Temperature,° F
C1035	As-rolled	43.9	80.2	30.0	60.7	45
A285	As-rolled	28.9	60.2	33.5	64.0	68
A201	As-rolled	37.7	65.2	33.5	65.1	26
A212	As-rolled	41.8	83.4	28.0	55.8	80
A203	As-rolled	52.5	80.9	29.5	63.1	28
A302(OR)	As-rolled	81.4	102.0	22.5	59.2	38
A302(TY)	As-rolled	71.3	104.0	18.5	50.5	30
A387	Annealed	39.4	67.8	33.7[a]	...	[b]
A357	Annealed	38.0	66.2	34.0[a]	...	—25
HY-65	Annealed	...	...	...	...	—5
T-1	Q & T	106.0	121.0	20.5	68.5	—162

[a] Elongation in 2 in., %.
[b] As brine quenched +80° F. Brine quenched and tempered —88° F.

ence, previous work[2] had indicated that test results which are in conflict with expectations can occur in alloy steels under certain conditions. Experiments related to this anomaly served as a starting point for the investigation.

A Cr-Mo steel, A357, (see Tables 1A, 1B) exhibited an increase in transition temperature when welding was performed with application of preheat.[2] For A357, the recommended weld metal employed for the specimen is very brittle. It initiates cleavage at such low bend angles and loads that crack arrest occurs after only a very limited amount of propagation. It was suspected that the unusually low crack-propagating force associated with such early initiation might be responsible for the anomalous result obtained. Attempts were made, therefore, to increase this force without altering the specimen, by means of a revised loading system. In addition, tests were undertaken in which the strain concentration at the weld was eased by removing the bead reinforcement.

Loading Method

The Kinzel specimen is normally loaded by means of a single tup at mid-span. When a crack propagates, the load on the specimen relaxes to an extent determined by the elasticity of the system. Because the crosshead of the tensile-test machine sustains a high value of load with little deflection, it is unloaded, and crack arrest allowed, by a very small relaxation of the specimen. On a static basis, mounting of the tup on a crosshead of greater flexibility would decrease the amount of unloading per unit length of crack propagation. Dynamically, however, this would require that the crosshead accelerate, on crack initiation, at a prohibitive rate to maintain the load above the minimum value necessary for crack propagation.

A system having increased energy storage without excessive inertia was obtained by applying the load at the third points of the specimen by means of a "double tup." A single tup acts to concentrate strain at the notch and to force the brittle area of the weld zone to initiate cleavage at lower values of load than would otherwise be the case. Two tups placed at the third points of the span allow higher loads to be achieved before crack initiation. Therefore, the crack-propagating force is greater than for the single-tup system. Also, the area of maximum tension stress is extended longitudinally by the distance between the tups. This allows a greater relaxation to occur before the tension stress is reduced to below the minimum required for crack propagation.

If the crack occurs immediately on first yielding of the specimen (zero ductility) with the single tup, application of the double tup will produce no change in the measurements obtained. However, for more ductile cases, the lowered strain concentration at the notch with the double tup delays initiation beyond the point at which it occurred with the single tup, just as if a more notch-tough weld zone were under test.

This effect of the double tup was shown by tests on identical specimens with both tup arrangements. For example, in Figs. 1a and 1b, the lateral contractions at original cleavage initiation (open circles) are greater for the double tup (about 0.5%) than for the single tup (about 0.25%) even for this case of moderately low ductility in the weld zone. The total contractions (filled circles) at failure show that the crack is propagated further by the double tup, since crack arrest is absent at 30 and 40° F. This confirms the idea that the force available to propagate the crack is directly related to the load at crack initiation.[2] The most important observation is that the greater lateral contraction at original initiation is equivalent to a weld zone of *greater* notch toughness; yet the transition temperature *increased* (about 20° F.) instead of decreasing, as would be expected. Therefore, in parallel with the results obtained on preheated A357 specimens (which were expected to be more notch tough than unpreheated), an observed increase in notch ductility in the weld zone was accompanied by an *increase* in transition temperature,

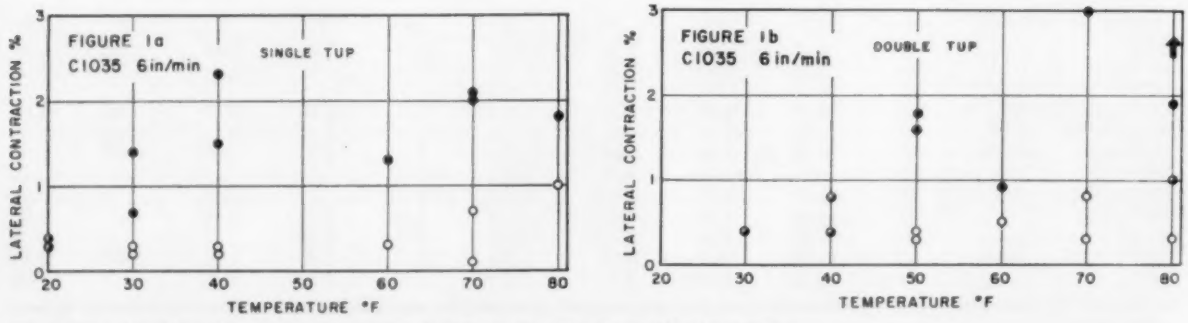

Fig. 1—Kinzel-test transition data for 1-in. 1035 steel illustrating the effect of the double tup

and here the effect was produced by mechanical means.

It was evident that the response of weld zones of other levels of notch ductility would require similar study. Because the stress system produced by the double tup frequently caused failure outside the notch, a simpler means of producing the same effect was sought.

Removal of Weld-bead Reinforcement

The geometry of the weld-bead reinforcement was suspected to intensify the notch severity in the region of the weld and foster earlier crack initiation at that point. Accordingly, tests of various steels were conducted with the reinforcement in place and with the reinforcement removed. Table 2 and Figs. 2, 3, 4 and 5 present representative data.

Figures 2 and 3 show the effect of the bead reinforcement on A203 steel welded at 6 and 10 ipm. In Fig. 2a it is evident that, in specimens retaining the bead reinforcement, crack arrest occurred at 20° F. The lateral contraction at cleavage initiation was 0.8%. An additional 1.2% occurred before reinitiation to give a total of 2% at failure. Figure 2b shows that specimens

Table 2—Summary of Kinzel Tests Showing Effects of Welding Conditions and Weld-bead Reinforcement

Steel	Welding travel speed, ipm	1% lateral contraction transition temperature, ° F Reinforcement on	Reinforcement off	Transition temperature determined by	Remarks
1035	6	30	...	Crack arrest	...
1035	6	...	40	Crack arrest	...
1035	6	50	...	Crack arrest	Double tup
1035	6	...	40	First initiation	Double tup
1035	6	40	...	Crack arrest	600° F preheat
1035	6	—60	...	First initiation	1150° F postheat
1035	10	35	...	Crack arrest	...
1035	10	...	50	First initiation	...
1035	10	...	40	First initiation	Double tup
1035	10	40	...	Crack arrest	400° F preheat
A285	6	10	...	Crack arrest	...
A285	6	...	—60	First initiation	...
A285	10	10	...	First initiation	...
A285	10	...	—20	First initiation	...
A212	6	80	...	Crack arrest	...
A212	6	...	70	First initiation	...
A212	10	130	...	Crack arrest	...
A212	10	...	80	First initiation	...
A203	6	20	...	Crack arrest	...
A203	6	...	—20	First initiation	...
A203	10	10	...	Crack arrest	...
A203	10	...	30	Crack arrest	...
A302	6	115	...	First initiation	...
A302	6	...	50	First initiation	...
A302	10	100	...	First initiation	...
A302	10	...	80	First initiation	...

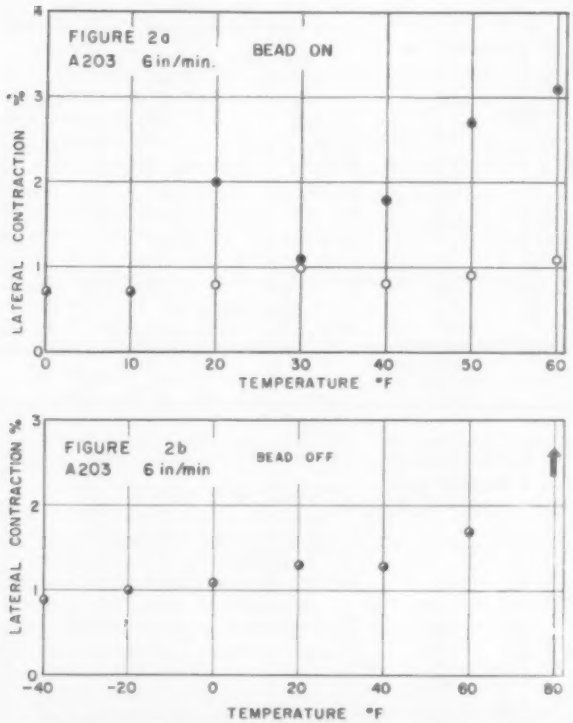

Fig. 2—Kinzel-test transition data for 1-in. A203 steel illustrating the effect of removal of the weld reinforcement. Travel speed 6 in./min

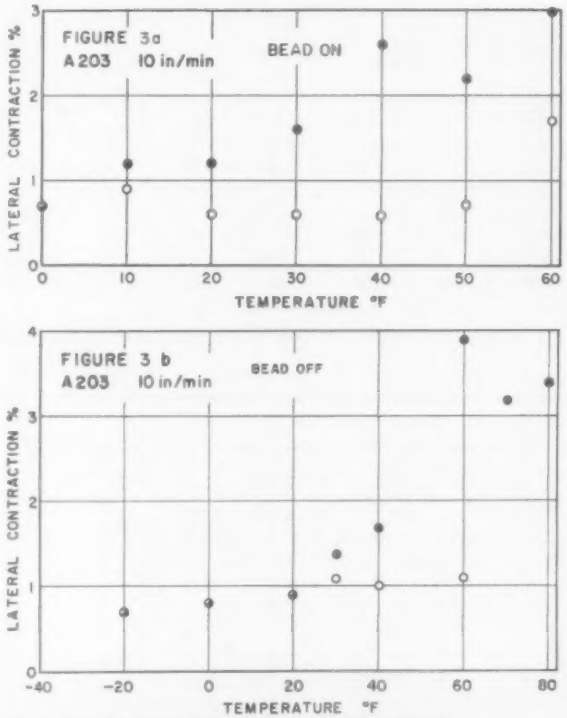

Fig. 3—Kinzel-test transition data for 1-in. A203 steel illustrating the effect of removal of the weld reinforcement. Travel speed 10 in./min

with the reinforcement removed deformed 1.3% at 20° F. before cleavage initiation, but here no arrest occurred. Note, however, that the 1% lateral-contraction temperature was −20° F. for specimens without reinforcement and +20° F. for those with reinforcement. Removal of the reinforcement lowered the transition temperature because it raised the lateral contraction before cleavage initiation. At the same time, it raised the crack-arrest temperature because it permitted higher loads and energy storage at the instant of cleavage initiation which favored complete cleavage propagation. Even at 60° F., arrest failed to occur.

Figure 3 shows a different relation of crack initiation, arrest and transition temperature. Again, removal of the reinforcement raised both the lateral contraction before cleavage initiation and also the lowest temperature where crack arrest was possible. In this case, however, contraction before initiation remained less than 1%, and the transition temperature was defined by the crack arrest. Thus the transition temperature was *raised* from +10 to +30° F.

The over-all relation of crack initiation, crack arrest and transition temperature may be catalogued into three cases by an analysis of the test data in Table 2. If both transition temperatures being compared in a given steel are determined by crack arrest (Case 1), the weld zone of greater notch ductility will invariably exhibit the higher transition temperature. If the increase in notch ductility of the weld zone changes the determinant to initiation (Case 2), the change in transition temperature can be variously an increase, decrease or no change, any specific combination being easily explained on the basis outlined above. In Case 3, both transition temperatures are determined by initiation and the weld zone of greater notch ductility invariably exhibits the lower transition temperature. The data for A212 steel shown in Figs. 4 and 5 are provided as an example of the plain-carbon class of steels. The results are both Case 2 (decrease).

Size of Weld

The purpose of changing weld heat input in the Kinzel test, on a given steel, is primarily to learn whether changes in the weld thermal cycle cause significant changes in the microstructure of the heat-affected zone and, thereby, alter the transition temperature. With the metallurgical changes, there are unavoidable changes in the size of the bead reinforcement and the volume of heat-affected zone, which may also influence the behavior of the test.

In order to separate the metallurgical and geometrical effects, series of specimens were prepared with the weld bead deposited at an angle of 60 deg to the axis of the specimen. The notch, therefore, cut through twice the normal length of reinforcement and heat-affected zone. A comparison of the results on standard specimens with those of 60 deg slant-weld tests is given in Table 3, for three steels, 1035, A302 and A212. The tests with the reinforcement removed showed essentially no effect of slanting the weld, and thus no effect of increasing the volume of heat-affected zone in this manner.

From the results on the specimens retaining the weld reinforcement, it appears that the wider reinforcement provided by the 60 deg slant weld did not increase the restraint on the weld zone but, indeed, somewhat reduced it. All of the steels but the 1035 showed a lowering of the transition temperature. The 1035 showed a slight increase because the crack-arrest temperature

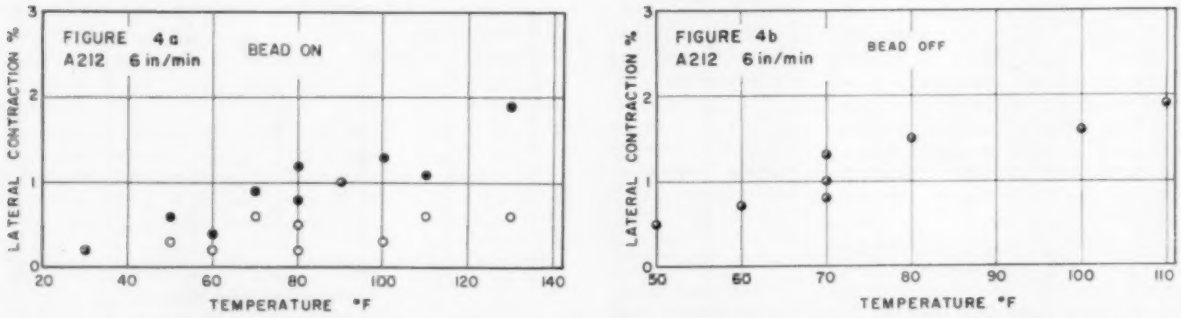

Fig. 4—Kinzel-test transition data for 1-in. A212 steel illustrating the effect of removal of the weld reinforcement. Travel speed 6 in./min

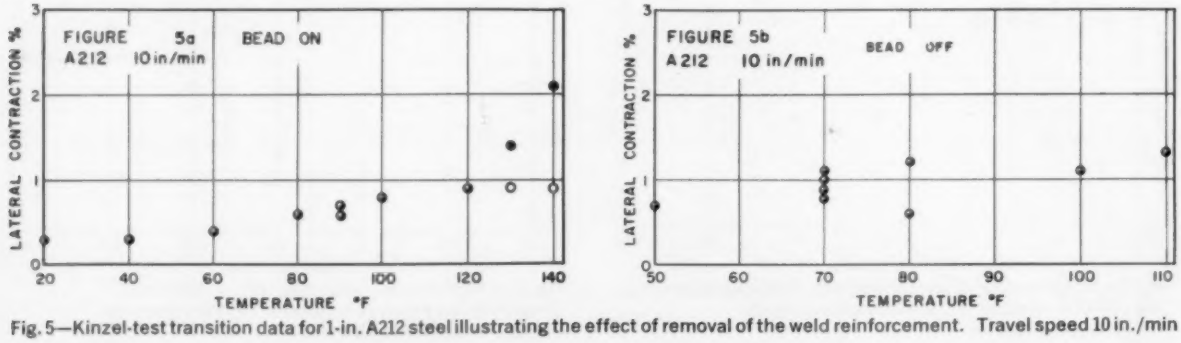

Fig. 5—Kinzel-test transition data for 1-in. A212 steel illustrating the effect of removal of the weld reinforcement. Travel speed 10 in./min

was raised by the higher driving load at crack initiation, by the same action described under effect of the reinforcement. It therefore seems reasonable to conclude that restraint increases with the height of the reinforcement but decreases with the width.

Modification of Kinzel Test to Determine Weld-zone Embrittlement

The extensive observations obtained on the behavior of the Kinzel test suggest a modification of the test method which may furnish useful information on the properties of the weld metal and heat-affected zone. In this sense, it would then become more directly a weldability test.

As presently conducted, the Kinzel test exhibits a transition temperature controlled by the combined action of the weld zone and the base metal. The specimen will fail in a brittle fashion, with less than 1% lateral contraction, if the weld zone initiates a cleavage crack and the base metal allows it to propagate without arrest. If the temperature is raised until either of these actions do not occur, the transition is reached. Some as-welded steels show a cleavage ring under the weld which persists well above the transition temperature. Postheated specimens are usually greatly toughened because the weld zone resists cleavage initiation, not because the base metal has been improved.

As the tests described previously show, changes in toughness in the weld heat-affected zone do not always produce corresponding changes in the over-all toughness of the specimen as measured by the transition temperature. Consequently, highly brittle zones can be present in the steel which are not reflected in the test results, unless careful examination of fracture surfaces is included. Because these zones can develop cleavage cracks at temperatures above the steel transition temperature, it is desirable in critical applications to select welding conditions which will minimize the embrittlement.

Cleavage initiation in the weld zone is easily detected in the Kinzel test by an audible click and a hesitation or drop-off in loading. The proposal is to stop the test at the first audible click or decrease in load. Lateral contraction would then be measured, and the notch ductility of the weld zone would be determined by the temperature of 1% contraction. A further important procedure would be to remove the weld reinforcement before testing. Since welding conditions will be varied deliberately to select the best conditions, the geometrical variable introduced by the reinforcement should be eliminated. This conforms to good fabrication practice.

Table 3—Comparison of Standard Kinzel Specimens with 60-deg Slant Weld Specimens

Steel and condition	1% lateral contraction transition temperature, ° F	Transition temperature determined by
A. Tests with bead reinforcement retained		
1035, 10 ipm travel speed		
Standard	35	Crack arrest
60-deg slant	55	First initiation
1035 6 ipm travel speed		
Standard	30	Crack arrest
60-deg slant	55	Crack arrest
A212 6 ipm travel speed		
Standard	80	Crack arrest
60-deg slant	60	First initiation
A302 10 ipm travel speed		
Standard	100	First initiation
60-deg slant	60	First initiation
A302 6 ipm travel speed		
Standard	115	First initiation
60-deg slant	60	First initiation
B. Tests with bead reinforcement removed		
1035 10 ipm travel speed		
Standard	50	First initiation
60-deg slant	50	First initiation
1035 6 ipm travel speed		
Standard	40	Crack arrest
60-deg slant	35	First initiation
A212 6 ipm travel speed		
Standard	70	First initiation
60-deg slant	40	First initiation
A302 6 ipm travel speed		
Standard	10	First initiation
60-deg slant	10	First initiation

Table 4—Relative Response of the Modified Test and the Standard Kinzel Test to Changes in Welding Conditions

Steel	Welding travel speed ipm	Modified test 1% lateral contraction temperature[a], ° F	Kinzel test 1% lateral contraction temperature[b], ° F
A285	10	−20	+10
	6	−60	+10
A212	10	+80	+130
	6	+70	80
A203	10	+30	+10
	6	−20	+20
A302	10	+80	+100
	6	+50	+115

[a] Measured at first cleavage initiation.
[b] Measured when load drops to one-half maximum load.

Table 5—Effect of Plate Thickness on NDT of Drop-Weight Specimens Welded as 1-in. plates (3-deg Stop Distance)

Steel	NDT of 1-in. plates, ° F	NDT of $^1/_2$-in. plates, ° F
A201	+10	−40
A212	+50	−20
A302 (heat TY)	+20	−80
A302 (heat OR)	+60	−30
A203	−60	−90
T-1	−100	−120

Table 4 shows the transition temperatures observed under the modified test procedure as compared to those of standard tests. The metallurgical difference between the heat-affected zones produced by a change in the welding travel speed is clearly and truly shown by the modified test wherein the mechanical effect of bead reinforcement is absent. The modified test thus should provide a relatively easy method of establishing (*a*) the best combination of electrode, heat input, preheat and postheat to provide a weld zone of maximum notch ductility in any given steel (lowest transition temperature), and (*b*) a better understanding of the effects of changes in welding variables, such as heat input and temperatures for pre- and postheating, and of how these effects vary with the chemistry and conditions of steels.

The Drop-weight Test

The nil-ductility transition temperature (NDT) of the drop-weight test, like the Charpy V-notch tran-

sition temperature, is intended to be a measure characteristic of the unwelded material.[3] The specimen is unique in its use of a separate metal, applied by arc welding, as a crack starter. While the effect of welding is not a test variable, it is nevertheless a factor in the test conditions and was included in the list of variables considered in the present work. These also covered the geometrical factors of stop distance, and specimen thickness and width.

Specimen Width

Steels A201 and A212 were tested using specimen widths of 2, 3½ and 6 in. The NDT's for these widths in A201 were 30, 10 and 10° F and for A212 were 60, 50 and 40° F respectively. From these results, it appears that the principal effect of specimen width in the range studied is to control the length of the fracture path necessary to fail the complete surface and establish the NDT. The wider the specimen, the lower the temperature necessary to permit the cleavage crack to reach the tension-surface edge.

Specimen Thickness and Deflection

Six steels were tested at 1- and ½-in. thickness. To maintain welding variables constant, the steels were welded at 1-in. thickness and part of the group was split to ½ in. for testing. Results are listed in Table 5. The NDT for 3 deg deflection was lower for ½-in. thickness in all cases, varying from a decrease of 20° F for T-1 to 100° F for A302(TY). This was the expected trend since the outer fiber strain imposed by a given deflection is decreased in proportion to the reduction in thickness. The major point was to determine whether the NDT for ½-in. thick specimens could be increased to that of the 1-in. thick specimens simply by increasing the stop distance and, with it, the outer fiber strain.

Steels A201 and A302(TY) were tested in ½-in. thickness (welded at 1 in. and split) with deflections up to 13 deg, at which their NDT values were still 30 and 20° F lower, respectively, than the NDT for the 1-in. thick specimens tested at 3 deg deflection. Considerable scatter of fracture behavior was observed at values of deflection of 8 deg or above.

If the proper stop distance is chosen, the NDT defines the temperature which divides the brittle and ductile segments of the idealized transition curve (deflection required to cause crack propagation versus temperature). Thus, a slight increase in temperature above the NDT should require more deflection in order to fracture the complete face of the specimen. Conversely, adjusting the machine to a greater allowable deflection should result in a higher NDT. In the present case, even if the breaking temperature for ½-in. thick specimens could be raised to the NDT for the 1-in. thick specimens by great increases in allowable deflection, it would no longer be a nil-ductility transition since excessive deformation would be imposed. The necessary interpretation is, therefore, that the upper limit of the brittle range for the given material is at a lower temperature for ½-in. thick specimens than for 1-in. thick specimens; a size effect is operative. This was also noted to be true for the recommended[4] 2- x 5-in. specimens tested on a 4-in. span, for which NDT values were up to 30° F below those for 1-in. thick specimens.

Weld-metal Hardness

In order to study the possible effects of variations in the weld-metal hardness on NDT, it was necessary to utilize a base plate which would produce a heat-affected zone under the weld bead that was virtually the same for all welding conditions. A low-carbon steel, such as A285, is best for this purpose.

Variations in the conditions of welding included travel speed and plate temperature. Table 6 contains the results of these tests. Only those travel speeds and plate temperatures which caused the weld metal to cool slowly enough to drop in hardness appreciably below R_c40 affected the NDT. Softer weld metal lowered the NDT of A285 plate as much as 90° when the hardness fell to R_c32. With a less-brittle crack source, crack propagation reached the edges of the specimen only with the use of much lower temperatures.

The thickness of the specimen welded can affect the weld-metal hardness significantly. The weld metal hardness of 1-in. A285 specimens was about R_c42, while for ½-in. specimens cut from the same plate it was almost 10 points softer. Thus it is desirable to reduce the heat input proportionately when welding plates under 1-in. thickness so that the weld-metal hardness will not fall below R_c40.

Heat-affected Zone

Generally, welding produces some regions in the heat-affected zone that are toughened as well as some that are embrittled. These toughened regions can occur where the welding tempers the base plate (below the A_1), where it refines the grain size markedly (just above the A_3), or near the fusion line where a fully martensitic and, thus, relatively tough structure may form in the case of low-alloy, low-carbon steels. The toughened zones have been shown to affect the Kinzel test, and apparently can affect the drop-weight-test behavior also.

Tests were conducted to determine the effect of a tough heat-affected zone on the NDT. Specimens of 1-in. A212 steel were water-quenched from 1600° F and

Table 6—Effect of Hard-surfacing Bead Hardness on the NDT of the Drop-weight Test—1-In. Plate Thickness—3 deg Stop Distance

Steel	Plate temperature, ° F	Weld travel speed[a], ipm	Bead hardness, Rc	NDT, ° F
A285	RT	10	40	+30
	RT	5	42	+30
	RT	2⅝	40	+40
	250	5	39	+40
	350	5	35	+10
	500	5	32	−60
A212	RT	10	44	+50
	RT	5	44	+50
	RT	2⅝	41	+50
	250	5	41	+50
	350	5	36	+50
	500	5	34	+30
A302(OR)	RT	10	42	−10
	RT	5	44	+60
	RT	2⅝	38	+50
	250	5	44	0
	350	5	41	−20
	500	5	35	−80

[a] Standard welding speed for 1-in. plate is 5 ipm.

welded for testing. A second set was first welded and then austenitized and water quenched. The base plates and weld metals were matched in these two series, but the heat-affected zone was absent from the welded and quenched series. The welded and quenched series showed an NDT of 100° F, while the quenched and welded showed one of 60° F. The presence of the heat-affected zone lowered the NDT 40° and produced a visible ring of shear under the weld bead, where the plate was tempered.

In usual tests on as-rolled and as-normalized A302 and A203 steels, marked rings of shear were likewise observed. Figure 6 shows the shearing observed in the A203 steel. Thus, it seems likely that in steels in which shear can be developed under the weld bead, the NDT is not completely independent of the influence of the heat-affected zone. The NDT temperatures of the steels were also observed to fall below the Charpy-V 15 ft-lb temperatures, which is unusual for these alloy steels.

Comparison of Kinzel and Drop-weight Transition Temperatures

An extensive series of specimens was prepared from the steels available to determine the degree of correlation between the Kinzel 1% lateral-contraction transition and the drop-weight NDT. The steels tested were heat treated by annealing, normalizing or oil quenching to furnish additional conditions for comparison. The extent of correlation is shown in Fig. 7.

For the most part, there is a fairly good correlation on a one-to-one basis between the tests. The large departures from the average curve occur only in a few alloy steels. From the analysis of the tests given above, it appears that scatter is likely in steels which develop a fairly tough heat-affected zone. In the Kinzel test, such a zone delays cleavage initiation and, by supplying higher driving energies, pushes the crack-arrest temperature upward. In the drop-weight test, the tough zone slows or arrests the cleavage crack of the weld metal and thus tends to depress the NDT. Examination of the fractures of the drop-weight specimen is desirable in order to detect when this action in the heat-affected zone is taking place.

Summary

The results of this investigation can be summarized as follows:

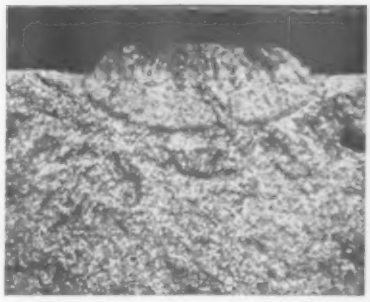

Fig. 6—Photograph of fracture surface of as-rolled 1-in. A203 drop-weight specimen broken at the NDT.

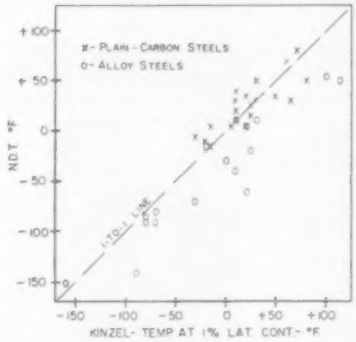

Fig. 7—Plot showing degree of correlation between standard (6 in./min) Kinzel 1% lateral-contraction transition temperature, and the NDT of the drop-weight test

1. Transition temperature in the Kinzel test is determined by the combined effect of the bead-weld region and the base plate. Tough weld zones, such as those obtained by postheating, produce relatively low transition temperatures in a given steel. Less tough weld zones, resulting from less favorable welding conditions, raise progressively the transition temperature exhibited by the test, up to a maximum temperature above which the steel cannot propagate cleavage. Further embrittlement of the weld zone then produces a lowering of the transition temperature, because it triggers cleavage too early to store enough elastic energy in the specimen to propagate the crack extensively unless the temperature is lowered.

2. In carbon structural steels, the coarse-grained heat-affected zone is usually brittle compared to the unaffected base plate. A 1% lateral contraction is therefore obtained only at temperatures sufficiently high for the steel to arrest cleavage momentarily. Thus the Kinzel transition temperature is base-plate controlled, and tends to correlate with the drop-weight NDT, also base-plate controlled.

3. Low-carbon alloy structural steels may form relatively notch-tough heat-affected zones, such as low-carbon martensite. This type of zone tends to delay crack initiation and, thus, provide the elastic drive to suppress crack arrest in the Kinzel test to higher temperatures. This causes the Kinzel transition temperature to occur considerably above the drop-weight NDT, which is lowered by a heat-affected zone capable of interrupting cleavage initiated by the hard-surfacing bead.

4. The Kinzel test can be modified to measure directly the notch-ductility of the weld zone. This is done by removing the weld reinforcement and measuring the lateral contraction at the first cleavage initiation. The specimen cannot exhibit 1% lateral contraction by this criterion unless the weld zone itself resists cleavage initiation to that level of deformation. Thus, the test then becomes a weldability test, specific to the zone adjacent to the weld, and by it welding conditions can be developed for optimum weld-zone notch ductility.

5. The height of the weld reinforcement on the Kinzel specimen decreases resistance to crack initiation, but the width of the reinforcement increases it.

6. The drop-weight-test NDT may be lowered by reductions in the plate thickness or hard-surfacing-bead hardness. If a portion of the heat-affected zone is tougher than the base plate, it can lower the NDT by forming a shear ring around the bead.

Acknowledgment

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Welding of Galvanized Steel— Cracking Mechanisms and Development of Solutions

Literature review and experimental program aimed at developing welding procedures which would result in crack-free fillet welds

BY JOHN F. RUDY

SUMMARY. The problem of root cracking encountered during the welding of galvanized steel is analyzed and, drawing upon related literature, fundamental explanation of the observations is derived. Critical experiments were performed to substantiate the mechanism of zinc penetration into the stressed weld-root area; and critical welding experiments were performed which were designed to eliminate those factors responsible for the phenomenon. These latter experiments included primarily (1) attempts to deposit "pure" iron rather than the typical E6010 deposition which contains appreciable amounts of alloy strengthening additions, and (2) attempts to alter the stress-concentration geometry at the root of the fillet by controlled weld-bead penetration and by opening the faying plane "notch." The second of these two techniques appeared to offer more promise as a means of controlling the zinc-cracking problem; however, its adoption will require some revised thinking on the merit of root penetration for fillet welds.

Introduction

The marked absence in the literature of any report concerning an extended research on the problem of welding galvanized steel might suggest that no difficulty has been encountered. However, recent attempts by the New York Naval Shipyard to develop a "qualified products list" for AWS type E6010 electrodes, for performing the tee fillet weld shown in Fig. 1 on galvanized plate, have not been successful.[1] In performing the required fillet-weld tests, a high incidence of "zinc penetrators" or galvanized cracks was observed in the neighborhood of the fillet throat. Figure 2 shows several typical photographs of this flaw. The penetrators have several characteristics: (1) They are observed with only this particular weld geometry, i.e., one which includes a galvanized faying surface at the weld throat in addition to the more exposed galvanized surfaces along the "legs" of the fillet. (2) The penetrators always have the appearance of having progressed from the weld root, with the deeper penetrations being spade-shaped from the root line (Fig. 2). (3) The problem is encountered with only relatively thick ($^1/_2$ in. or greater) steel plates. (4) The penetrations appear to follow an intergranular path.

The objective of this program was to develop welding procedures which would result in crack-free fillet welds. "Welding procedures" involved two general areas of experimentation—i.e., to develop a special-purpose electrode which is not susceptible to zinc penetration, or to develop a deposition technique which would allow commercially available electrodes to meet requirements. A "special-purpose" electrode could be adapted to this particular problem either by adjusting its deposited-metal analysis to allow for the zinc effects or by altering the deposition, or "built-in operator technique," characteristics.

For an intelligent choice of desirable deposit analyses and deposition techniques, it was necessary to arrive at some explanation of the mechanism of zinc cracking. A literature survey coupled with critical experiments suggested the following.

Discussion of the Mechanism

The penetrators, or cracks, are observed by depositing a single-pass fillet weld as shown in Fig. 1. The fillet is then fractured by folding the plates toward the fillet; this causes a tearing fracture through the throat of the fillet. If a zinc crack is present, the throat fracture follows this plane of weakness and the fracture surface reveals a zinc-coated area (Fig. 2). Over an 18-in. long fillet sample, zinc pene-

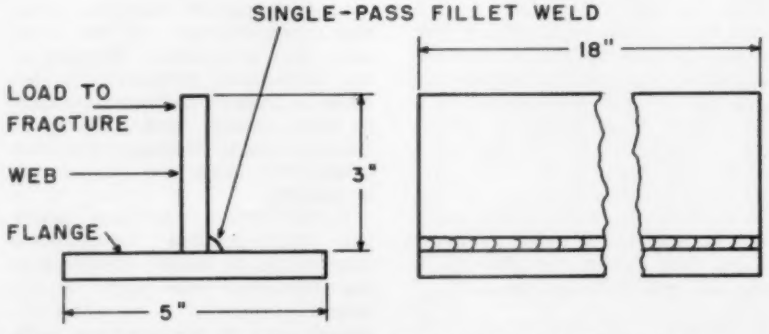

Fig. 1—Tee section joined by fillet weld. The weld is tested by folding the web as shown. Material is HTS steel galvanized on all surfaces

JOHN F. RUDY is associated with the Metals Division of Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill.

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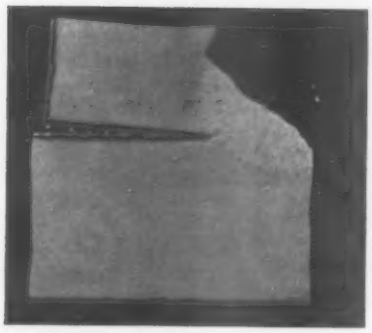
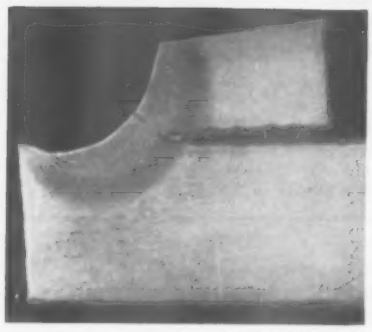


Small root crack, X3



Through crack, X3

Fracture surface X1

Fig. 2—Typical zinc cracks in fillet welds. The light areas in the fracture surface are the galvanized crack surfaces which were brought out by heat tinting at 625° F, 30 min in air. (Reduced by approx. 1/3 upon reproduction)

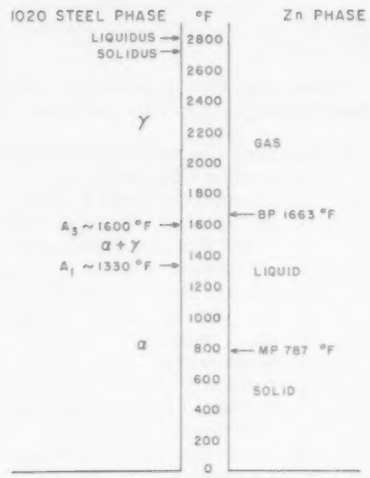


Fig. 3—Illustration of the phases of steel and zinc which can exist at the temperatures experienced during deposition of a weld bead.

trator evidence was observed, during the course of experimentation, an accumulative distance varying from zero to as much as 12 in.

The zinc penetrators obviously result from some sort of an interaction between the weld-deposit steel and the surface layer of zinc. Consideration of respective melting and boiling temperatures, with the aid of Fig. 3, shows the possible phase-interaction combinations which may exist between these two metals as the deposited weld metal cools to room temperatures. At temperatures in excess of the melting point of steel, zinc exists only as a gas and can be observed to bubble through the weld puddle. These bubbles are sometimes entrapped, and porosity results. However, this gaseous zinc cannot directly explain the cracking problem since the galvanized penetrator surface does not exhibit the smooth and spherical appearance of a gas entrapment. A possible indirect mechanism by which gaseous zinc could cause the penetrator flaw requires that the zinc be dissolved by the molten steel and be rejected to the grain boundaries during solidification. There are several known characteristics of the flaw, however, which suggest that such is not the case. First, the requirement for faying-surface zinc rather than exposed-surface zinc. If zinc-vapor bubbles could dissolve and cause the flaw, any weld geometries involving exposed zinc surfaces would show some signs of degradation—for example, a full penetration butt weld between two galvanized-steel plates. However, observations suggest a particular geometry requirement. Also a general grain boundary rejection does not explain the appearance of the penetrators, which start from the throat and progress only partially to the surface. General rejection should place the zinc at the top centerline of the "casting" similar to the occurrence of low-melting constituents in an ingot. Therefore it is concluded that the critical steel-zinc interaction occurs at a lower temperature, after the zinc becomes liquefied. According to Fig. 3, liquid zinc exists only at temperatures well below the solidification temperature of the steel weld puddle. Thus the greatest likelihood for finding a cracking mechanism appears to involve a solid steel–liquid zinc interaction.

Considering the liquid zinc–solid steel interaction possibility, the mechanism would be grain boundary penetration by liquid zinc. The observed dependence on base plate thickness suggests that cooling stresses are a factor; hence, "stress-corrosion" mechanisms could obtain.

W. A. Morgan,[2] drawing heavily on the work of C. S. Smith[3] and other literature as well as his own experimental work, gives the following general description of the mechanism of stress corrosion of metals by liquid metals. Figure 4 illustrates the interface tensile-force system that must be balanced at the grain boundary–liquid metal junction (point O). The parameters are the surface tension forces *A*, *B* and *C* which are brought into balance by

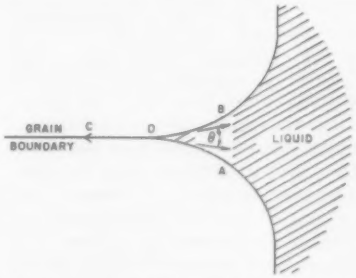


Fig. 4—Relation between grain-boundary surface tension (C) and solid-liquid surface tension (A and B). The dihedral angle (θ) is adjusted such that the force system is balanced

an adjustment of the dihedral angle θ. When *C* is much larger than *A* and *B*, θ diminishes causing a sharp, deep penetration of the liquid metal into the solid metal grain boundary. Stress contributes to this picture in two ways: (1) increasing grain-boundary surface tension (*C*) which promotes liquid penetration, and (2) possibly initiating a root fracture if the diffusion-product alloy at the notch has much poorer mechanical properties than the base metal.

The general liquid-solid metal stress-corrosion failure sequence was shown to be as follows:

1. A dihedral angle θ is formed.
2. Diffusion occurs rapidly into the stressed grain boundary.
3. The stresses, which are of the order of yield point, cause an intergranular crack to initiate.
4. Liquid metal is pulled into the crack capillary, and diffusion continues.

5. This penetration continues until an intergranular fracture occurs.

There are two possibilities for modifying this fracture sequence:

1. Increase the solid–liquid surface tension (A and B).
   (*a*) Change the solid surface, for example, by oxidizing or by inducing a compressive stress.
   (*b*) Change the composition of the liquid metal. This may require a complete substitution since minor additions (to Zn) will not appreciably change the surface tension (A and B).
2. Decrease the grain-boundary surface tension (C).
   (*a*) Change the composition of the solid metal. Generally, solution-strengthened metals are more susceptible apparently because the alloy strengthening increases microstresses in the grain boundaries.
   (*b*) Reduce macrostress for similar reasons.

A more recent explanation of the mechanism of cracking in the presence of liquid zinc does not require the formation of a sharp dihedral angle (θ) or of grain-boundary diffusion.[4] According to this later theory, the presence of liquid metal allows a brittle fracture to occur at relatively low imposed stresses due to the fact that the surface energies created in this system are appreciably lower than the comparable energies with no liquid metal present. However, the modification possibilities according to this theory, i.e., relative surface-energy values and imposed stresses, are essentially the same as before.

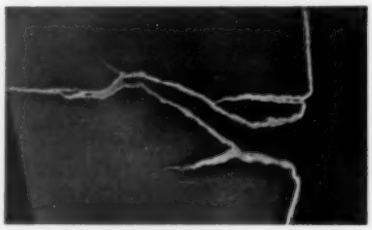
How do the foregoing general discussions, which evolved primarily from experimentation on the Cu-Bi and the Al-Hg systems, apply to this particular steel-Zn problem? The welding situation is parallel in that the faying plane provides a capillary reservoir of liquid zinc which can operate at the stressed fillet throat, the throat area being stressed transversely (to yield-point magnitude) by weld-zone cooling through the critical temperature range. The data of Radeker[5] are interesting in consideration of the particular interaction of liquid zinc and stressed steel. He worked with four steels—i.e., Armco iron, low Si boiler plate, high Si (about 0.30%) boiler plate and a low-alloy higher-strength steel containing Cu and Ni. U-bend specimens were made of $^1/_2$-in.

Table 1—End Distance at Crack Initiation of Steel Bend Specimens in 475° C Zinc[5]

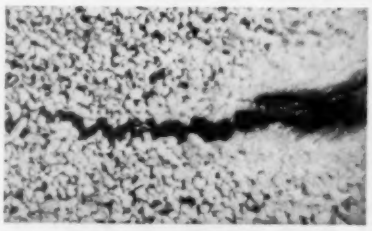
Notch radius	Mm				
	∞	4	2	1	0.05
Armco iron	0	0	0	0	0
Low Si	0	0	0	0	0
High Si	0	7	2	0	6
Low alloy	0	15	10	5	9

square bars of each steel. The specimens were bent to a radius of approximately $1^1/_2 \times t$ and immersed in a bath of Zn at 475° C with the bending clamp still in place. Table 1 gives his results with 5 degrees of stress concentration (notch sharpness on the tension side varying from infinity to <0.05 mm radii) for each of the four steels. If the specimen did not crack within a few seconds after immersion, the clamp was slowly closed to zero-end distance. Zero-end distance indicates no crack was observed. These results show the necessity for a stress concentration and also the increasing crack susceptibility with increasing alloy addition to the steel. Radeker further showed no marked temperature effect in the range 425 to 500° C. The cracks which were observed are microstructurally similar to fillet-root cracks with welded galvanized plate.

The bend-specimen tests of Radeker were duplicated by the author with similar results. Figure 5 shows the crack caused in a U-bend specimen by zinc penetration which initiated at the throat of a notch in a weld-overlay deposit. A photomicrograph in Fig. 5 shows the intergranular path of the crack front.



X3



X250

Fig. 5—A zinc-penetration crack obtained by immersion of a notched-and-stressed weld-overlay specimen in a zinc bath. Note the intergranular path of the crack front. (Reduced by $^2/_3$ upon reproduction)

Thus the available evidence indicates "stress-corrosion" of the solidified weld bead by faying-surface liquid zinc as the mechanism for the observed zinc penetration. Assuming this mechanism to obtain, possible solutions to the problem include:

1. Removing the faying-surface zinc.
2. Removing the stress or, more practically, removing the stress concentration by designing the joint to eliminate the notch.
3. Depositing a low-alloy weld metal—ideally, pure iron.

Welding Electrodes

The greatest part of the experimental work involved the evaluation of the zinc-throat penetrator behavior of approximately 45 commercial brands of welding electrodes which included AWS classifications E4520, E6010, E6011, E6012, E6013 E6020, E7010, E7016, E10010, E10013 and E10016, as well as several nickel-base and stainless-steel electrodes and 9 special formulations directed toward obtaining pure-iron deposits.

Each electrode was deposited on galvanized HTS steel to form the tee joint (shown in Fig. 1) with at least two different arc currents. The 18-in. fracture surface was observed for evidence of zinc penetration. The aggregate length of crack for the whole specimen divided by the specimen length became the measure of zinc penetration, expressed herein as "percent zinc crack." For example, the fracture surface of the specimen shown in Fig. 2 measures approximately 58% cracking. The dependence of this index on the welding-electrode type is shown by the following.

E6010 Electrodes. Since the zinc-penetrator problem was initially encountered during attempted qualification of E6010 electrodes, this type serves as the basis of performance comparison. A total of 7 commercial and 4 special representatives of this electrode class were evaluated. The results of the E6010 evaluation are summarized in Table 2 which shows an average, for the class, of 36% zinc penetration. Averages of each commerical electrode within the class ranged from 23 to 49%, with individual specimens scattering from 11% to as high as 80%. Welding current and travel speed were varied over a wide heat-input range; the effects of

these parameter changes are discussed below.

As a class, E6010 electrodes gave an average deposited-metal analysis (with the subject joint design) of 0.15% C, 0.40% Mn and 0.15% Si with no consistent, wide departures from these average values. Within the obtained analysis range, no cracking dependence on chemistry can be noted.

E6011 Electrodes. The two E6011 commercial electrodes evaluated gave results which were similar to the E6010 class, although some reduction of zinc cracking can be noted (see Table 3). Also, the Mn content of these electrodes was lower (0.24%) than that of the E6010 electrodes (0.40%).

E7010 Electrodes. This class is also very similar, as expected, to the E6010 class of electrodes.

E6012 and E6013 Electrodes. The most significant dependence of zinc-cracking index on electrode type is observed with the lower penetration E6012 and E6013 (also an E6013 iron powder—E6027) classes, as shown in Table 3. The data for the three classes are very similar and may be discussed together. Their average indexes are only 10, 8 and 0%, respectively. Weld-metal chemistry analysis showed C and Mn to be similar to E6010 types, but the E6013 deposit did have slightly more silicon. The probable cause of the relative success of these electrodes, however, is not attributed to deposit chemistry, but to their characteristic low-heat or low-penetration behavior. Low penetration causes reduced corner penetration, which is advantageous for the avoidance of the cracking problem. This dependence upon penetration has been observed by Stern and Nagler,[1] and has been shown by the author's data as presented in Fig. 6.

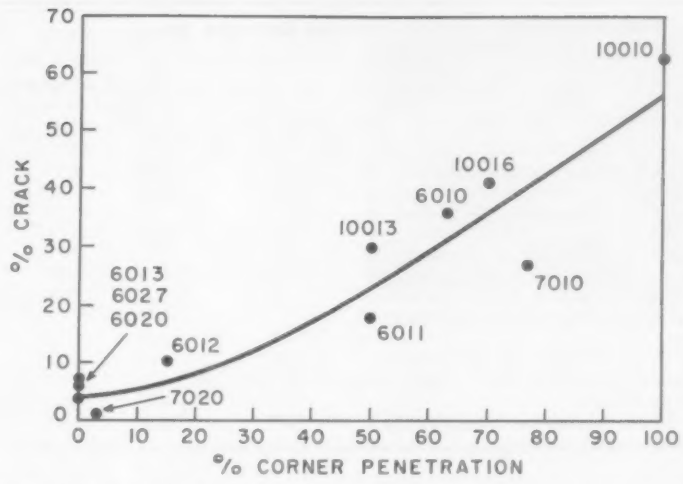


Fig. 6—Electrode penetration vs. degree of cracking. Penetration is expressed in terms of the lineal percent of the web corner at the root of the weld which was fused

Figure 7 illustrates a low-penetration fillet, made with an E6012 electrode, compared with an E6010 weld. This is an extreme case but it is apparent that the faying-plane

Table 2—Performance of E6010 Electrodes for Fillet Welding 1/2-in. Galvanized Steel

Manufacturer code	No. of specimens	Extent of zinc cracking, % Avg	Min	Max	Representative weld-deposit analyses, Wt % C	Mn	Si
A	8	46	22	80	0.12	0.49	0.16
B-1	3	33	26	51	0.10	0.31	0.12
B-2[a]	4	36	23	50	0.10	0.40	0.12
C-1	2	23	22	24	0.21	...	...
C-2	3	49	40	65	0.14	0.31	0.17
D	3	28	12	40	0.14	0.41	0.14
E	3	28	11	36	0.10	0.47	0.18
Average		36					

[a] Iron-powder modification.

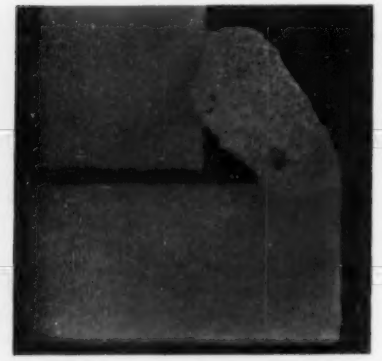
Table 3—Performance of Various Electrode Types for Fillet Welding 1/2-in. Galvanized Steel

AWS classification	No. of commercial representatives	Extent of zinc cracking, % Avg	Min	Max	Representative weld-deposit composition, wt % C	Mn.	Si
E6010	7	36	23	49	0.10–0.20	0.35–0.45	0.12–0.18
E7010	3	27	24	34	0.10–0.15	0.40–0.45	0.16–0.17
E6011	2	18	17	20	0.08	0.24	0.11
E6012	6	10	3	13	0.10	0.32	0.13
E6013	3	8	0	16	0.06–0.14	0.38–0.46	0.23–0.39
E6027[a]	1	0	..	..	0.07	0.31	0.05
E10010	1	63	..	..	0.19	0.57	0.18
E10013	1	30	..	..	0.13	0.33	0.18
E10016	1	42	..	..	0.09	1.37	0.45
E7016	1	10	..	..	0.14	0.67	0.32
E6020	1	4	..	..	0.14	0.39	0.09
E7020	2	1	0	3	0.10	0.45	0.15

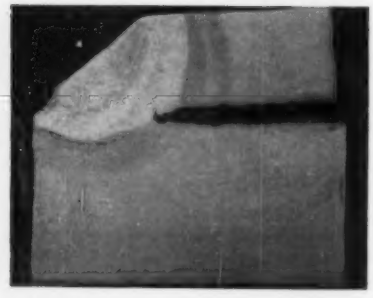
[a] E6013 iron powder.

Table 4—Performance of Special-formulation Electrodes for Fillet Welding 1/2-in. Galvanized Steel

Description	Extent of zinc cracking, %	Representative weld deposit composition, Wt % C	Mn	Sn
Mfr. A, E6010 covering, Armco-iron wire	30	0.15	0.57	0.20
Mfr. B, E6010 covering, Armco-iron wire	10	0.10	0.41	0.12
Mfr. A, E6010 with low Mn, Si covering, Armco-iron wire	34	0.11	0.13	0.13
Mfr. B, E6010 with low Mn, Si covering, Armco iron wire	7	0.06	0.09	0.07
Mfr. B, E6012 covering, Armco-iron wire	9	0.06	0.05	0.06
Mfr. B, E6012 with low Mn, Si covering, Armco-iron wire	11	0.08	0.35	0.11
Bare Armco-iron wire, inert-gas shielded	1	0.03	0.22	0.02
European commercial equiv. to AWS E4520, low penetration	1	0.04	0.03	0.04
Commercial "Armco-iron" electrode	27	0.06	0.14	0.39



E6012. X3

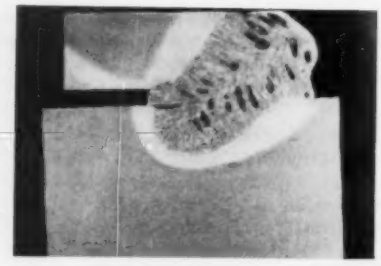


E6010. X3

Fig. 7—Comparison of the deep-penetration E6010 weld deposit and the shallow E6012 deposit. The E6012 deposit does not fuse the corner of the web plate. (Reduced by 1/2 upon reproduction)

zinc reservoir is sufficiently removed from the root of the weld. Other examples of E6010 welds are pictured in Fig. 2.

E6020 and E7020 Electrodes. The heavier slag, medium-penetration EXX20 electrodes show improvement in zinc-cracking behavior (Table 3). The "medium-penetration" characteristic was sufficiently shallow to enable weld-metal deposition without fusing the corner of the web plate. Nothing in the comparative weld-metal analyses suggested any "chemistry" explanation of this improved behavior.



X3

Fig. 8—Inert-gas shielded, bare Armco-iron weld deposit showing excessive porosity. (Reduced by 1/2 upon reproduction)

Low-hydrogen Electrodes. The single E7016 low-hydrogen electrode evaluated performed comparably to the E6012 class. The fact that the three specimens welded with this electrode exhibited little corner fusion may explain the improved behavior.

Higher-strength Electrodes. According to our basic understanding of the phenomenon of liquid-metal penetration into grain boundaries, increasing the solid-metal matrix strength by alloying additions renders the metal more susceptible to attack. The high-strength electrode data support this contention. Of the three higher-strength electrodes evaluated (Table 3), E10013 and E10016 offer good measures of the effect of solid-metal strengthening *per se*, since their moderate strength counterparts, E6013 and E7016, exhibited a low cracking susceptibility. The high-strength modifications average 30 and 42% zinc penetration, respectively. A similar effect is shown with the strengthening of the EXX10 electrodes which were made more susceptible by addition of strengthening elements (36 and 63% zinc penetration for E6010 and E10010, respectively).

Special-formulation Electrodes. The proposed zinc-penetration mechanism suggests that improvement may be obtained by reducing the strength level of weld deposit. The optimum weld deposit, by this argument, is pure iron, which should be least susceptible to cracking. However, obtaining "pure" iron in a weld deposit is complicated by the requirement for weld-puddle deoxidization. The most common deoxidizers are manganese and silicon, both weld-metal strengtheners. Since, for this reason, no "pure" iron-depositing electrode is commercially available, special low-alloy formulations were requested of two electrode manufacturers. These formulations plus several other low-alloy commercial products are described in Table 4. The first two electrodes, Armco-iron wires with the standard E6010 coverings of two manufacturers, have deposit compositions and performance characteristics which are similar to standard E6010 electrodes. This is as would be expected since the major part of the deoxidizer-alloy addition and the penetration behavior are functions of the covering rather than the wire. Both manufacturers then supplied similar electrodes with "Mn- and Si-bearing constituents adjusted to minimum values consistent with other electrode requirements." Deposit analyses indicated that these elements were indeed reduced. However, only the "manufacturer B" electrode behaved appreciably better than the E6010 class average. This electrode exhibited less penetration than both the comparable manufacturer A electrode, and the E6010 class as a whole.

Two other special formulations were obtained from manufacturer B (the fifth and sixth entries, Table 4) which were based on an EXX12 covering. Both of these behaved appreciably better than the E6010's, but not appreciably better than the commercial E6012 electrodes. The important factor, considering individual results of the several specimens, was corner penetration.

Bare Armco-iron wire was deposited under inert-gas shielding to evaluate the effect of filler-metal composition *per se*. The deposit analysis, of course, reflects base-metal dilution, but manganese and silicon contents are relatively low. Figure 8 shows the excessive porosity obtained, but essentially no zinc cracking was observed.

A European electrode, possessing unusually low-penetration characteristics, and also depositing unusually pure iron, was evaluated as shown (Table 4) and gave essentially no zinc cracking. This electrode was so "cold", however, that difficulty was experienced in obtaining adequate fillet-leg fusion.

The last "special" was a commercial covered "Armco-iron" electrode. Its deposit analysis showed appreciable manganese and silicon; therefore, it offers no composition advantage for this purpose. Its zinc-cracking behavior was similar to that of the E-6010 class.

Welding Technique

To a certain extent, the operator technique is built into the electrode covering; for example, an E6010 weld deposit will exhibit deeper penetration than an E6012, with any normal operator technique. However, it is possible to further alter these deposition factors by means of controlling the arc heat and weld-puddle position and by changing the joint design. Several such techniques were evaluated as reported below.

According to the proposed mechanism of zinc penetration, zinc enters the stressed weld-root grain boundaries from the faying-plane zinc reservoir. Effective technique variations would therefore be expected to alter geometry, stress, or time-temperature relationships at the weld root, not necessarily at the galvanized surfaces along the legs of the fillet. This supposition was verified by two experiments: (1) a tee joint was performed between two ungalvanized steel plates, with a *0.010-in. zinc shim inserted in the faying plane;* (2) a tee joint was performed between two galvanized plates, the "leg surface" zinc having been previously removed by an excursion of a carbon arc or an oxyacetylene flame. Both experiments resulted in zinc penetration into the root of the fillet to a degree which was comparable to that obtained with the normal (all surfaces galvanized) welding procedure. Therefore, the effective technique variations are those which alter the freezing and cooling situation at the root of the fillet. Figure 6, showing the relationship between zinc cracking into the root of the fillet and weld-bead penetration into the root corner, was included to illustrate an important "built-in-technique" variation inherent with the E6012, E6013 and E6020 electrodes. The following experiments were attempts to obtain a similar fillet-root geometry with E6010-type electrodes.

Table 5—Incidence of Zinc Root Cracking with and Without a Faying-plane Spacer[a]

Electrode class	Extent of zinc cracking, %[b]	
	Tight fit	1/16-in. spacer
E6010	36	8
E7010	27	12
E6011	18	6
E6012	10	2
E6013	8	2
E6027	0	..

[a] Compare Fig. 1 with Fig.9.
[b] Average found for each class.

The most successful means of consistently altering root geometry was by spacing the faying surfaces as shown in Fig. 9. In this study, the gap was maintained by insertion of a 1/16-in. shim as shown but cross wires or any other spacers would be just as effective and possibly more convenient. This joint resulted in an appreciable reduction of the zinc penetrator problem as illustrated for all electrodes in Table 5. The reduction of extent of zinc cracking —from an E6010 class average of 36% of lineal weld length to 8%— is significant. The reduction of the E6012 electrodes from 10 to 2% is also significant.

Welding-current variations between approximately 160 and 210 amp did not show an appreciable effect on zinc penetration. This can be partially explained by the tendency of the operator to compensate with a welding travel-speed adjustment. However, heat input, measured by current/travel speed, also showed no significant effect over the range of variation experienced.

Penetration should be a function of arc length, but unusually long arcs have other disadvantages and therefore were not evaluated. A few welds were made with the electrode angled 70 deg. from the vertical. This technique did reduce bead penetration, and zinc penetration was reduced from an average of 42% (with that particular E6010 electrode) to only 1%. However, puddle control was difficult.

Summary and Conclusions

The following conclusions are suggested by a review of pertinent literature, which has been referenced, and by the experimental program.

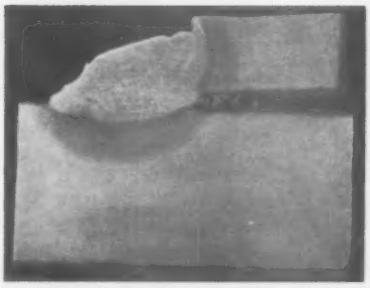
1. The "zinc-cracking" problem in the welding of galvanized steel is observed only with a particular weld joint, namely, a tee fillet weld between plates ≥ 1/2 in. thick, wherein the faying plane at the weld root contains zinc. The requirement for 1/2 in. thickness probably involves weld restraint considerations as well as the effectiveness of the faying surface as a zinc reservoir.

2. The mechanism of the formation of zinc penetrators is akin to "stress corrosion" of cooling steel by liquid zinc. Stress levels of yield-point magnitude are required, as is a stress-concentration geometry. When liquid zinc is in contact with steel under these conditions, a rapid penetration into the grain boundaries occurs. There is some doubt as to whether the zinc penetrates the grain boundary as a diffusing impurity of the steel or as liquid zinc. The latter mechanism is the most recently proposed.

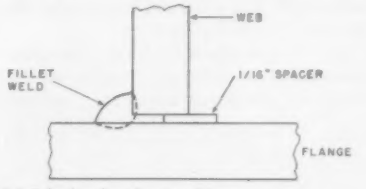
3. This type of liquid-metal penetration of grain boundary results from the relative surface tensions of the grain boundary (steel-to-steel) and the zinc-to-steel interface. Addition of alloys to the liquid metal (zinc) probably will not appreciably change this relationship, according to the theory, although this was not demonstrated.

4. Additions of alloying elements which strengthen the steel enhance the phenomenon; pure iron, therefore, is the least susceptible to zinc penetration.

5. It is difficult to obtain a relatively pure-iron weld-metal deposit—first, because of weld-metal dilution and, secondly, because of the requirement for deoxidization as a means of controlling weld-metal porosity. The deoxidizers most frequently included in commercial electrodes are Mn and Si, both of which are potent strengtheners and are,



Weld cross section. Welded with spacer. X3



Joint design for above weld

Fig. 9—Faying-plane-spacer joint design. (Photomicrograph reduced by 1/2 upon reproduction)

therefore, undesirable for present purposes. Perhaps a covering development utilizing nonstrengthening deoxidizers, such as the mischmetals would prove fruitful.

6. Attempts to obtain low Mn and Si weld deposits led to special formulation electrodes which deposited on the order of 0.10% Mn and 0.07% Si, compared to usual E6010 weld deposits on the order of 0.40% Mn and 0.15% Si. These deposits may have been somewhat less susceptible to zinc penetration, although any such evidence was obscured by side effects.

7. The incidence of zinc penetration can be markedly reduced by making those procedural adjustments which tend to prevent the formation of a notch at the weld bead corner. The two most effective procedural variations for this purpose were:

(*a*) the substitution of lower penetrating E6012 electrodes for E6010 and

(*b*) the placement of $^1/_{16}$-in. spacers within the faying plane.

The mechanism of this improvement probably involves both "zinc reservoir" effects and stress-pattern effects.

Acknowledgments

The author is gratefully indebted to the Bureau of Ships for financial support of this program, and to T. Griffin and L. Fink for helpful guidance during the course of the experimentation. Acknowledgment is also made of the assistance of J. Chyle and A. Clemens of the A. O. Smith Corp. and the Arcrods Corp., respectively, for their cooperation in supplying special-formulation electrodes.

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Selection of Projects

The **Welding Research Council** is receptive to new ideas for research projects from any source. Naturally before any project can be approved or undertaken, certain yardsticks have to be applied. For the most part there are rather obvious yardsticks developed over the years:

1. Is the **Welding Research Council** the best agency to undertake the work?
2. Is the problem a "doable" one?
3. Will it be possible to secure the necessary funds, talent and research facilities?
4. Is the problem of broad general interest?

The answer to question 1 is in most cases not too difficult as this question implies other questions:

(a) What other agencies are working in this general field?
(b) What work has already been done or is being done in the general field?
(c) Is there some other agency that could be considered a more logical agency?

Problem 2 is sometimes more difficult. The **Welding Research Council** believes, however, that before any experimental work is undertaken that a literature survey of existing information should be made by the investigator to learn what has been done before—the successes and failures. A breakdown of the problem into its fundamental elements should help provide this answer.

The answer to the third question, inasfar as funds are concerned, should be readily available. A project should not be undertaken unless the sponsors are willing to put up a third of the funds. In developing a program and budget one should have bids from at least two laboratories which in itself would provide part of the answer to this question. However the ideas of Committee members and the original sponsors should be secured.

The answer to the fourth question is generally available as the result of securing the answers to the first three questions.

Hot-Cracking Test for CO_2-Shielded Metal-Arc Welds

Objects of investigation are to develop a suitable hot-cracking test and to evaluate a series of welds made with Al-Mn-Si mild-steel wire compositions

By P. W. RAMSEY, R. A. KEIDEL AND J. N. KUHR

SUMMARY. There has been a need, for some time, for a quantitative hot-cracking test for use with gas-shielded consumable-electrode welding. Ideally, such a test should require a small amount of wire and yield reproducible values.

Such a quantitative test has been developed for evaluating the hot-cracking resistance of welds made with consumable electrodes. A tensile load is imposed on a small, 1/8- x 1 1/2- x 10-in. specimen and a transverse weld made under carefully controlled conditions so as to obtain 50–60% penetration. The test is repeated at successively higher stress levels until positive evidence of failure appears in the form of longitudinal cracks. The lowest stress at which such failure occurs is called the hot-cracking index.

The hot-cracking apparatus was evaluated using twenty-one Al-Mn-Si mild steel wire compositions and CO_2 shielding. The nominal composition used as a base for the series was: 0.16 C, 1.3 Mn, 0.54 Si, 0.48 Al, 0.010 P and 0.020 S. Individual elements varied over the following ranges: 0.05–0.24 C, 0.5–2.9 Mn, 0.01–0.50 Si, 0.1–0.9 Al, 0.010–0.54 P and 0.016–0.058 S.

Increasing the manganese content of the wire to a level of 1.5 or higher significantly improved hot-cracking performance. Sulfur did not show any deleterious effect on hot cracking, possibly due to the presence of large amounts of manganese. Phosphorus, in the narrow range explored, had no noticeable effect on hot cracking. Increasing carbon, silicon or aluminum was found to reduce hot-cracking resistance of the wire.

All-weld tensile tests showed that increasing manganese significantly improved strength properties with no sacrifice in ductility.

Introduction

Hot cracking in highly stressed weldments has been a problem associated with the freezing characteristics of the weld-metal composition.

P. W. RAMSEY, R. A. KEIDEL and J. N. KUHR are associated with the Welding Research Department, Research and Development Division, A. O. Smith Corp., Milwaukee, Wis.

Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., April 25–29, 1960.

The mechanism has been covered adequately in recent papers by Pellini[1, 2] and associates who attribute the hot cracking to low-melting grain-boundary segregates and the presence of tensile stresses. As the weld metal cools from the liquid state, segregates form at the grain boundaries, contraction occurs, and an interdendritic separation may result. Segregates with low-melting points that occur as films rather than globules are considered most damaging. Welds that are highly susceptible to hot cracking tend to form extensive longitudinal cracks. In some cases, cold cracks also may nucleate at small hot cracks.

The need for a quantitative test for evaluation of hot-cracking properties became apparent during the development of wires for CO_2-shielded welding. A survey of hot-cracking test methods revealed many qualitative tests which are both difficult to interpret and costly. An apparatus developed by Boudreau[3] for evaluation of sheet-material cracking sensitivity appeared adaptable to weld filler metal as well. The quantitative indices were reported to be reproducible, enabling comparisons among materials to be made.

Object

The objects of the present investigation were (1) to develop a hot-cracking test to evaluate gas-shielded consumable-electrode welds, and (2) to evaluate, under carefully controlled conditions, a series of welds made with Al-Mn-Si mild steel wire compositions, using CO_2 shielding.

Procedure

Hot-cracking Apparatus

Various test methods devised in the past for evaluating the hot-cracking tendencies of weld metal were more appropriate for manual welding than automatic welding. The tests reported by Boudreau[3] used automatic tungsten arc inert-gas equipment without the addition of filler metal. A 1/16- x 1 7/8- x 5 7/8-in. rectangular-plate specimen was held in a tensile loading clamp and the arc moved transversely across the specimen. Welding amperage, voltage and travel speed were held constant, as well as a dead-weight tensile load applied through a lever arm. In this way a steady, measurable stress was applied to the specimen during welding under conditions simulating not only the welding stresses, but also the subsequent thermal contraction and expansion. The load was progressively increased from test to test until a stress was attained at which cracking initiated.

Fig. 1—Hot-cracking apparatus setup for calibration tests; (A) calibration specimen centered between head and tail stock, (B) strain recorder

This apparatus and test procedure were modified to allow their use with automatic CO_2-shielded metal-arc welding. An apparatus to apply a dead-weight tensile load to a flat specimen was designed, as shown in Fig. 1, in which a 1/8- x 1 1/2- x 10-in. mild-steel specimen was secured by four pins between a fixed head stock and movable tail stock. The load was transmitted to the movable tail stock by means of a 10:1 lever arm. The head stock was made adjustable so that the lever arm could be positioned horizontally at the start of each test. A special support was also provided in

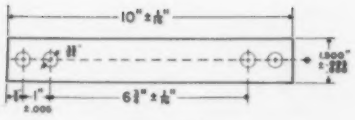

Fig. 2—Hot-cracking test specimen

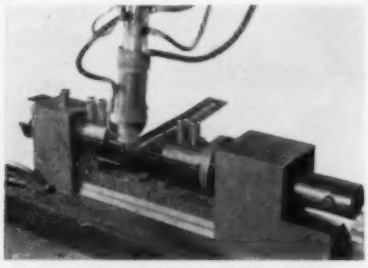
Fig. 3—Hot-cracking apparatus and specimen at completion of a test

the lever arm to hold the load prior to insertion of the test specimen in the grips. The movable tail stock, in turn, was supported by a ball bushing to minimize friction losses. Provision was also made for an adjustable copper backing plate which later proved unnecessary and was discarded.

Calibration

The lever system was calibrated using a standard specimen to which A-5 wire strain gages were attached. Gages were cemented on opposite sides of the calibration specimen and connected in series so as to cancel out bending strains. The specimen stress was found to be proportional to the applied weight and a calibration curve was subsequently used for calculating hot-cracking indices from the applied dead-weight loads.

Specimen

Specimens for the hot-cracking tests were prepared from a single heat of low-carbon steel, with analysis as indicated in Table 1. As shown in Fig. 2, specimens were machined to a width of 1.500/1.505 in., and a length of 10 $\pm 1/16$ in. Plate thickness was in the range 0.120/0.130 in.

Welding Conditions

Welding conditions were established using constant current, automatic equipment, $1/16$-in. commercial CO_2 welding wire,* 30 cfh of CO_2 shielding gas and direct current with

* Nominal composition—0.16 C, 1.1 Mn, 0.35 Si, 0.60 Al.

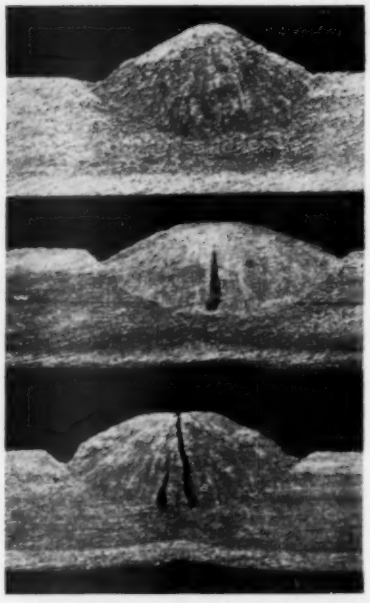
Fig. 4—Microstructure of hot-cracking test specimens showing effect of increasing tensile stress: top, no cracking—stress well below hot-cracking index; middle, internally cracked—stress slightly below index; bottom, internal crack visible as longitudinal surface crack—stress at hot-cracking index

Table 1—Composition of Wires, Welds and Plate Materials

Identification	—Wire and plate analysis, %—						—Single-pass weld analysis, %—						—Multipass weld analysis, %—					
	C	Mn	Si	Al	P	S	C	Mn	Si	Al	P	S	C	Mn	Si	Al	P	S
Standard wire																		
1A	0.16	1.28	0.54	0.48	0.010	0.025	0.13	0.74	0.28	0.23	0.036	0.028	..	..	..	..	..	..
Manganese-series wires																		
1C	0.18	0.64	0.31	0.67	0.012	0.027	0.14	0.46	0.18	0.27	0.036	0.023	..	..	..	..	..	..
2C	0.15	1.55	0.55	0.71	0.013	0.027	0.13	0.77	0.27	0.35	0.035	0.027	..	..	..	..	..	..
3C	0.18	1.85	0.46	0.73	0.018	0.023	0.12	0.88	0.23	0.27	0.035	0.032	..	..	..	..		..
4C	0.16	3.05	0.55	0.86	0.021	0.025	0.12	1.61	0.30	0.44	0.036	0.024	..	..	..	..	..	..
Aluminum-series wires																		
1B	0.18	1.10	0.43	nil	0.013	0.027	0.10	0.61	0.20	0.03	0.034	0.026	..	..	..	..	..	..
2B	0.18	1.20	0.44	0.17	0.014	0.022	0.10	0.59	0.22	0.04	0.034	0.026	..	..	..	..	..	..
3B	0.17	1.36	0.53	0.28	0.012	0.016	0.12	0.67	0.28	0.09	0.034	0.030	..	..	..	..	..	..
4B	0.18	1.32	0.56	0.88	0.011	0.026	0.13	0.71	0.30	0.46	0.034	0.027	..	..	..	..	..	..
Silicon-series wires																		
1J	0.20	1.17	0.01	0.62	0.007	0.025	0.13	0.59	0.14	0.25	0.009	0.028	0.08	0.77	0.09	0.28	0.007	0.028
2J	0.19	1.08	0.18	0.88	0.008	0.020	0.13	0.64	0.15	0.39	0.008	0.029	0.08	0.87	0.16	0.56	0.014	0.026
3J	0.20	0.85	0.50	0.61	0.005	0.023	0.14	0.59	0.25	0.32	0.011	0.029	0.08	0.66	0.24	0.34	0.004	0.027
Carbon-series wires																		
1H	0.05	1.17	0.46	0.64	0.004	0.028	0.12	0.60	0.24	0.30	0.015	0.028	0.06	0.82	0.27	0.38	0.006	0.028
2H	0.18	0.94	0.24	0.68	0.005	0.018	0.14	0.57	0.18	0.30	0.006	0.029	0.10	0.74	0.18	0.41	0.008	0.028
3Ha	0.24	1.48	0.56	0.75	0.006	0.031	0.14	0.66	0.28	0.12	0.010	0.044	0.12	0.98	0.33	0.29	0.007	0.027
Phosphorus-series wires																		
1K	0.15	1.32	0.44	0.64	0.046	0.030	0.12	0.62	0.27	0.04	0.051	0.032	0.09	0.82	0.26	0.23	0.053	0.024
2K	0.14	1.46	0.55	0.61	0.049	0.026	0.12	0.63	0.25	0.05	0.048	0.026	0.09	1.00	0.34	0.19	0.050	0.028
3K	0.13	1.48	0.48	0.67	0.049	0.029	0.11	0.67	0.24	0.09	0.055	0.028	0.09	0.83	0.29	0.17	0.055	0.028
Sulfur-series wires																		
2L	0.14	1.50	0.64	0.61	0.006	0.051	0.11	0.61	0.26	0.06	0.009	0.036	0.11	0.98	0.34	0.22	0.013	0.046
3L	0.13	1.73	0.74	0.67	0.015	0.059	0.14	0.63	0.32	0.07	0.010	0.040	0.11	1.08	0.37	0.22	0.005	0.051
4L	0.14	1.63	0.61	0.58	0.004	0.063	0.13	0.61	0.28	0.05	0.008	0.042	0.10	1.02	0.35	0.18	0.005	0.057
Plate																		
$1/4$-in. A-285 plate	0.17	0.52	0.04	..	0.020	0.026	..	..	..	..	..	..	..	..	..	..	..	..
$3/4$-in. A-285 plate	0.19	0.46	0.02	..	0.019	0.029	..	..	..	..	..	..	..	..	..	..	..	..
$1/8$-in. strip (hot-cracking test)	0.08	0.41	0.01	..	0.010	0.031	..	..	..	..	..	..	..	..	..	..	..	..

the electrode positive (DCRP). Starting and finishing plates were tack welded to the specimen to assure that arc conditions would be stable and uniform across the full width of the specimen, while not in any way interfering with the load application, and a typical test setup is shown in Fig. 3. Voltage and amperage conditions were modified as required to obtain 50–60% weld penetration, but were usually about 25 v and 300 amp. Travel speed was held constant at 71 to 72 ipm. A lead angle of 8 deg was found to give the best results.

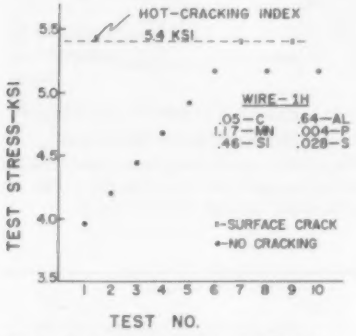

Fig. 5—Typical series of tests for determination of hot-cracking index of an experimental wire

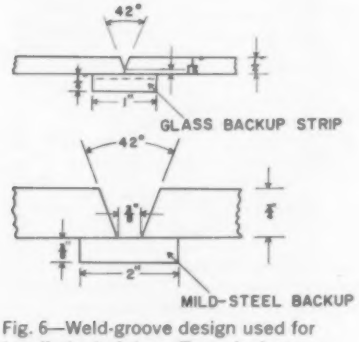

Fig. 6—Weld-groove design used for tensile-test plates: Top, single-pass weld; Bottom, multi-pass weld

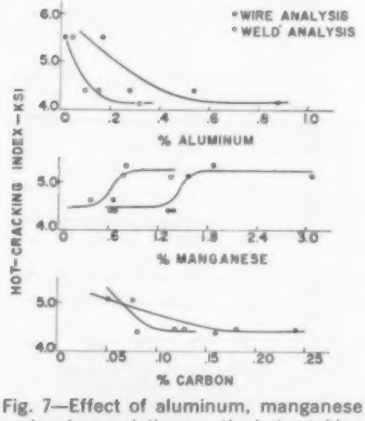

Fig. 7—Effect of aluminum, manganese and carbon variations on the hot-cracking index of CO_2 welds made with experimental Al-Mn-Si wires

Even at slightly lower stresses, however, it was found that dimpling occurred on the bottom of the specimen along the weld line. Cross sectioning revealed this was due to to internal cracking or separation in the weld metal with the formation of a void, as shown in Fig. 4. In all cases the hot cracks were found to originate at the weld-stock interface, and to progress upward to the weld surface where they became visible as longitudinal surface cracks at sufficiently high tensile loads.

A sufficient number of tests was made to bracket the stress at which visible surface cracking occurred, and this value was then designated the hot-cracking index, as shown in Fig. 5. In addition, the specimens were individually sectioned, polished and examined, and the penetration carefully measured.

Wire-development Program

A number of ten-pound induction melts were prepared in graphite crucibles and cast in 2-in. diameter x 12-in. ingot. The composition of these mild-steel heats was varied in a systematic manner in order to produce wires having a range of carbon, manganese, silicon, aluminum, phosphorus and sulfur contents. The nominal composition used as a base for the various experimental series was a melt having 0.16 C, 1.3 Mn, 0.54 Si, 0.48 Al, 0.010 P, 0 025 S. The variations in individual elements covered the ranges: 0.05–0.24 C, 0.5–2.9 Mn, 0.01–0.50 Si, 0.1–0.9 Al, 0.010–0.054 P and 0.016–0.058 S. Analyses of the wires and welds are shown in Table 1. The ingots were forged, swaged and then drawn to $^1/_{16}$-in. diam. welding wire.

In addition to hot-cracking indices described earlier, tensile properties also were determined for single- and multipass welds made in ASTM A-285 steel. Welds were made with constant-current automatic equipment with 30 cfh CO_2 as shielding gas, and a d-c power source with the electrode positive.

Single-pass welds were made in $^1/_4$-in. A-285 stock using a vee-groove joint preparation, 42-deg included angle, $^1/_{16}$-in. lip, with a glass backup. Amperage was 350 to 430, voltage 30 to 35, travel speed 20 to 22 ipm.

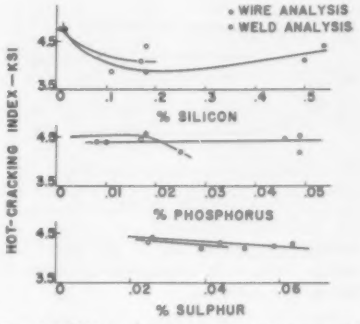

Fig. 8—Effect of silicon, phosphorus and sulfur variations on the hot-cracking index of CO_2 welds made with experimental Al-Mn-Si wires

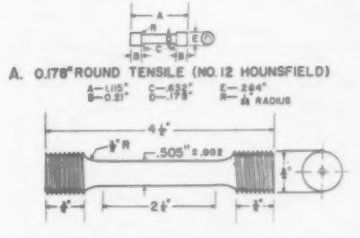

Fig. 9—Specimens used for all-weld tensile tests of single-pass (A) and multipass (B) welds

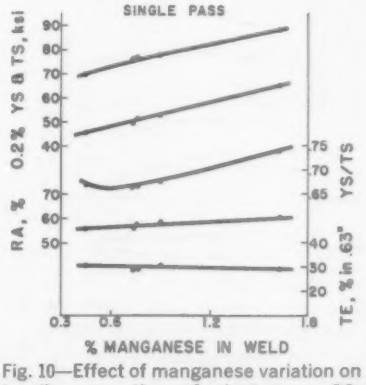

Fig. 10—Effect of manganese variation on tensile properties of single-pass CO_2 welds made with experimental Al-Mn-Si wires

Multipass welds were made with $^3/_4$-in. A-285 stock using a spaced vee-groove joint preparation, 42-deg included angle, $^3/_8$-in. gap, with a mild-steel backing. Amperage was 350 to 380, voltage 32 to 37, travel speed 12 ipm and welding was done with the electrode positive. Groove designs are shown in Fig. 6.

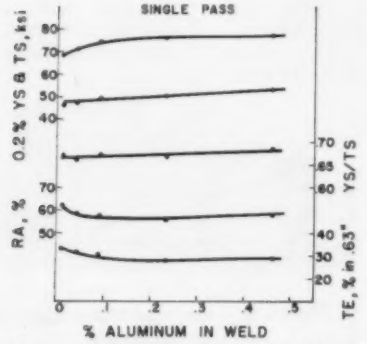

Fig. 11—Effect of aluminum variation on tensile properties of single-pass CO_2 welds made with experimental Al-Mn-Si wires

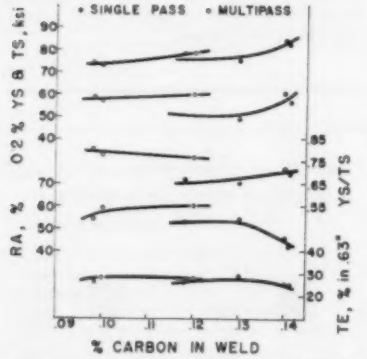

Fig. 12—Effect of carbon variation on tensile properties of CO_2 welds made with experimental Al-Mn-Si wires

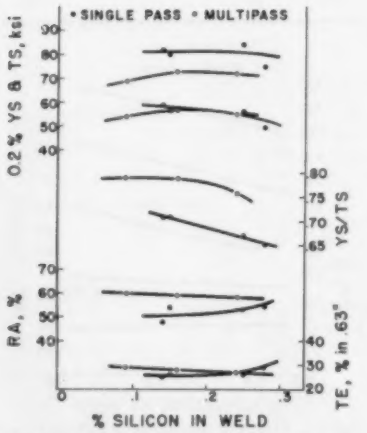

Fig. 13—Effect of silicon variation on tensile properties of CO_2 welds made with experimental Al-Mn-Si wires

Results and Discussion

Hot-cracking tests were made using the apparatus and procedures developed earlier, and the effect of compositional change can be seen in Figs. 7 and 8.

Miniature 0.178-in. diam. tensile specimens were used to determine mechanical properties of the single-pass welds, and round 0.505-in. diam. specimens for the multipass welds, as shown in Fig. 9. Tensile properties of single-pass and multipass welds will be found in Figs. 10 through 15.

The recoveries in the weld of various elements present in the wire, after transferring through the arc, are illustrated in Figs. 16 through 21.

Effects of Composition on Hot-cracking Index

Only manganese improved the resistance of this mild-steel, Al-Mn-Si, weld metal to hot-cracking, as evidenced by the marked increase in the hot-cracking index. Elements lowering its resistance included aluminum, silicon, carbon and, to a lesser degree, phosphorus and sulfur.

The effectiveness of manganese in combining with sulfur to form innocuous globular inclusions is well known, and in the particular composition and welding method studied, it appeared that a definite improvement in hot-cracking resistance occurred in wires containing more than 1.5% manganese, or welds of more than 0.75% manganese.

The presence of aluminum in more than minor amounts resulted in a lowering of the hot-cracking resistance, the threshold apparently is under 0.2% aluminum in the wire, and 0.1% aluminum in the weld. While there has been speculation that, in certain ranges, aluminum may produce grain-boundary Type II sulfide inclusions, none were detected in the metallographic studies made on the aluminum series of welds.

Increasing carbon also reduced the level of the hot-cracking index, with a fairly sharp change in the vicinity of 0.08% carbon in the weld. With this particular mild-steel plate stock having an 0.08% carbon level, it was necessary to hold 0.05% carbon in the wire to produce a weld having superior hot-cracking resistance. This is in accord with the tendency for increased carbon contents to accentuate segregational effects.

An increase in the silicon content generally lowered hot strength, but at higher levels of silicon this was not as marked.

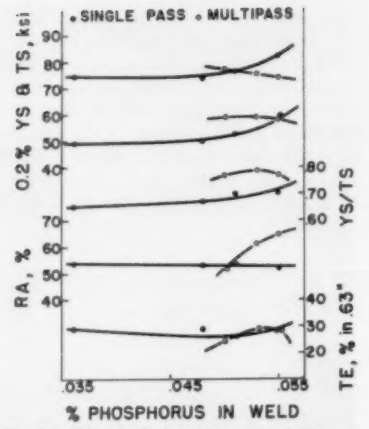

Fig. 14—Effect of phosphorus variation on tensile properties of CO_2 welds made with experimental Al-Mn-Si wires

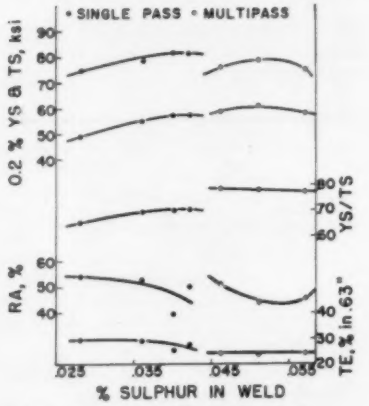

Fig. 15—Effect of sulfur variation on tensile properties of CO_2 welds made with experimental Al-Mn-Si wires

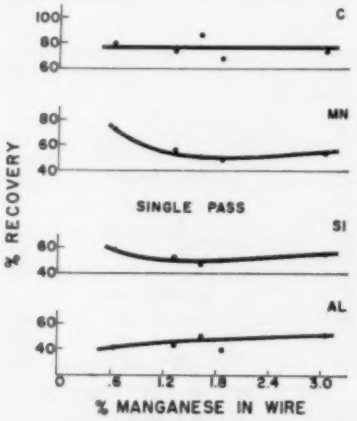

Fig. 16—Effect of manganese variation on the recovery of several elements in single-pass CO_2 welds made with experimental Al-Mn-Si wires

The phosphorus range was quite narrow, and the results do not appear of significance as to the effect on hot-cracking tendency.

Sulfur was varied over a much wider range, but possibly was rendered harmless due to the presence of a large manganese content, and hence did not show any marked effect on hot cracking. This is in contrast to recent work[4] on argon-shielded arc welding of 1% Cr-Mo steels, were the major cause of hot cracking was found to be the relatively highsulfur content of the steel.

Mechanical-Property Trends

Manganese was unique among the elements investigated in raising the strength levels of single-pass welds substantially, from 70 to 87 ksi, while maintaining ductility values close to 30%. An increase in the yield-tensile ratio also was noted, at the highest manganese level.

Moderate increases in strength and decreases in ductility were found with increasing aluminum, silicon or carbon.

Variations in sulfur or phosphorus had only minor effects on the tensile and ductility properties.

In all series, the yield-tensile ratios were higher for multipass welds than for single-pass welds.

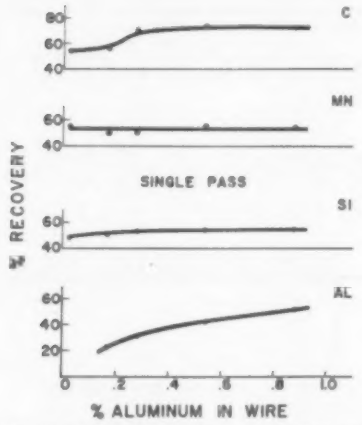

Fig. 17—Effect of aluminum variation on the recovery of several elements in single-pass CO_2 welds made with experimental Al-Mn-Si wires

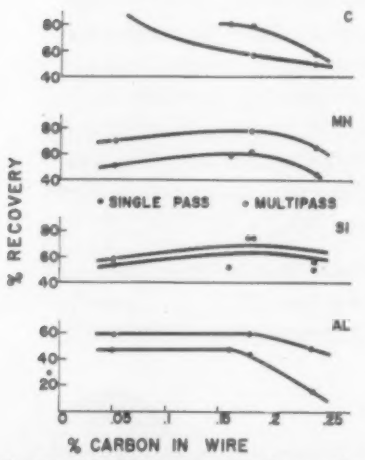

Fig. 18—Effect of carbon variation on the recovery of several elements in CO_2 welds made with experimental Al-Mn-Si wires

Recovery of Various Elements

As manganese content increased, it was less completely recovered in the weld metal, and otherwise showed but minor effect, on recoveries of aluminum, silicon or carbon.

Aluminum, as the most active deoxidizer present, showed low recovery until present in quite substantial amounts. When present in the wire at the 0.2% level, only about 25% was found in the resultant weld, but at a level of 0.8%, over 50% was recovered. Its presence also increased the recovery of carbon, but had no effect on silicon or manganese.

Carbon was found to transfer less completely at the 0.25% level, than at 0.15%. For reasons not clear, the recovery of aluminum, manganese and silicon also dropped in tests with the highest-carbon wire.

Silicon recovery dropped as silicon increased, but had no effect on aluminum, manganese or carbon.

Phosphorus and sulfur both showed a marked effect on aluminum recovery. At the highest levels of these elements, about 0.05–0.06%, recovery of aluminum dropped to about 10% in single-pass welds, and 30% in multipass welds. Changes in manganese, silicon and carbon were erratic, and followed no definite pattern.

In general, aluminum was found to be the principal deoxidizer, with manganese and silicon less effective in this regard. Aluminum also appeared to have some sensitivity to the presence of large amounts of phosphorus or sulfur, showing, in some cases, very low recovery in the weld metal.

Conclusions

1. A hot-cracking apparatus was developed which quantitatively evaluated the hot-cracking resistance of CO_2-shielded mild-steel welds, giving values which were reasonably reproducible.

2. Hot cracking was found to originate at the base of the weld at

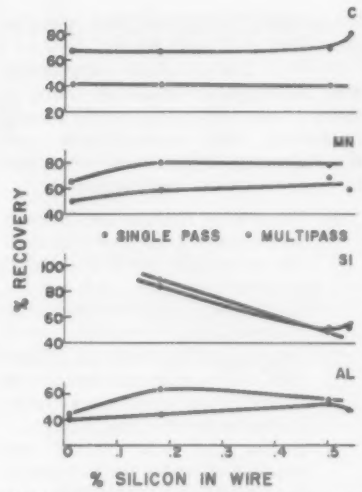

Fig. 19—Effect of silicon variation on the recovery of several elements in CO_2 welds made with experimental Al-Mn-Si wires

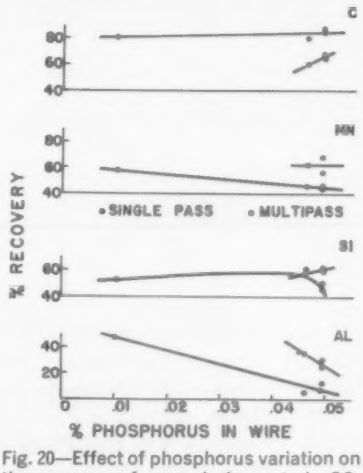

Fig. 20—Effect of phosphorus variation on the recovery of several elements in CO_2 welds made with experimental Al-Mn-Si wires

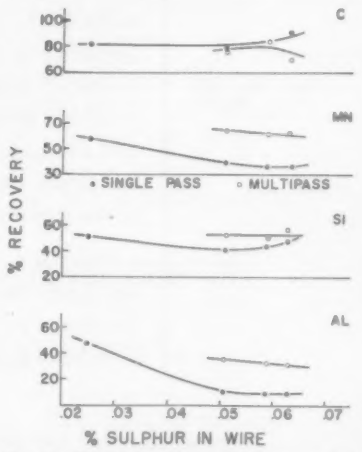

Fig. 21—Effect of sulfur variation on the recovery of several elements in CO_2 welds made with experimental Al-Mn-Si wires

the interface with the weld plate in every case.

3. The hot-cracking apparatus was thoroughly evaluated using a series of carefully prepared Al-Mn-Si mild-steel wire compositions, and the following trends were observed in hot-cracking performance:

(*a*) Increasing manganese content to a level of 1.50% or higher in the particular Al-Mn-Si mild-steel wire investigated, significantly improved hot-cracking performance.

(*b*) In general, an increase in carbon, silicon and aluminum was found to reduce the hot-cracking resistance of the wire.

(*c*) Sulfur did not exhibit any marked effect on the hot-cracking resistance, possibly due to the presence of large amounts of manganese.

(*d*) Phosphorus, in the narrow range explored, had no noticeable effect on hot cracking.

4. Mechanical property tests on welds made from these wires showed that increasing manganese significantly improved strength properties with no sacrifice in ductility. Results also showed that yield strength–tensile strength ratios were substantially higher for multipass than for single-pass welds.

5. Analysis of welds and wires showed lowest recovery for aluminum due to its strong deoxidizing properties. Recoveries of manganese and silicon were also higher than the aluminum.

Acknowledgments

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WRC BULLETIN NO. 58

Strength of Aluminum Alloy 6061-T4 Thick-Walled Cylindrical Vessels Subjected to Internal Pressures

Welding Research Council Bulletin #58, published in March 1960 describes a phase of the current research Project being sponsored by the Pressure Vessel Research Committee of the Council. This Project is being carried out at Pennsylvania State University under the direction of Professor J. Marin and under the guidance of the Subcommittee on Pressure Vessel Shell Theory to determine the validity of available theories for predicting the maximum pressure that can be applied to a thick-walled cylindrical vessel. Several materials are being investigated and various ratios of outside to inside diameters are being considered. The present paper deals with the portion of this investigation concerning the strength of vessels made of an aluminum alloy, 6061-T4.

The price of this Bulletin is $1.00 and single copies may be purchased through the American Welding Society, 33 West 39th Street, New York 18, N. Y. Quantity lots may be purchased through the Welding Research Council, 29 West 39th Street, New York 18, N. Y.

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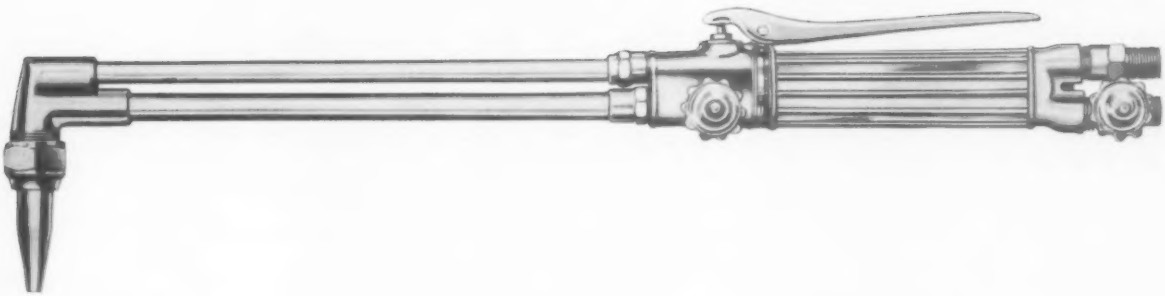

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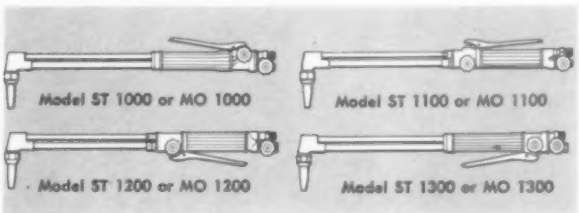

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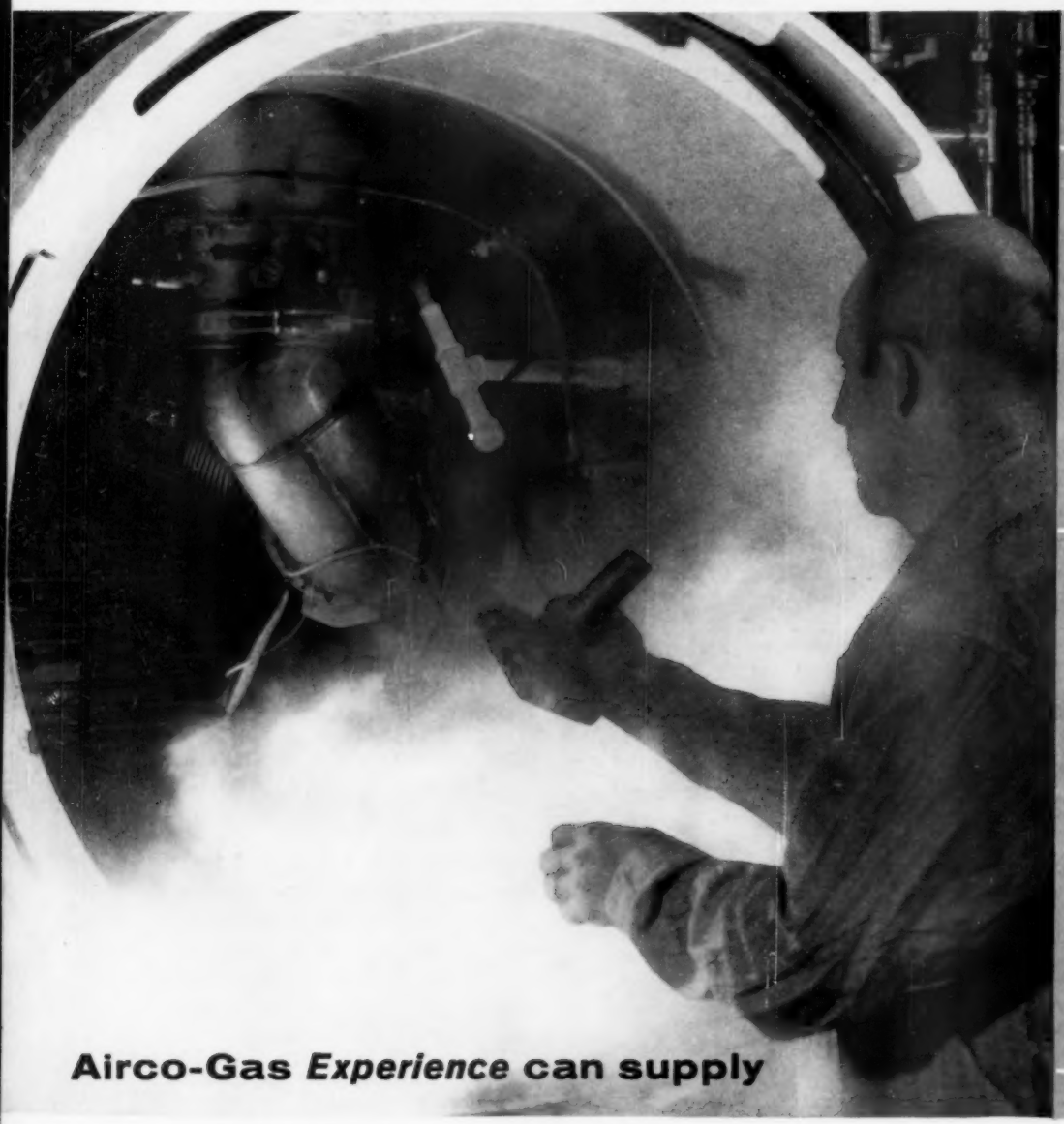

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